BACHELOR THESIS & COLLOQUIUM – ME 1841038

ACTIVITY-BASED FUEL OIL CONSUMPTION ESTIMATION FOR CALCULATING ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI) IN INDONESIAN MERCHANT SHIP

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DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
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SKRIPSI – ME 1841038

ESTIMASI KONSUMSI BAHAN BAKAR BERBASIS AKTIVITAS UNTUK PERHITUNGAN ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI) PADA KAPAL NIAGA INDONESIA

HARRIS PERDANA KUSUMA
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SURABAYA
2020

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APPROVAL FORM

ACTIVITY-BASED FUEL OIL CONSUMPTION ESTIMATION FOR CALCULATING ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI) IN INDONESIAN MERCHANT SHIP

BACHELOR THESIS

Submitted to Comply One of The Requirement to Obtain a Bachelor Engineering Degree

on

Marine Operation and Maintenance (MOM)

Bachelor Program Department of Marine Engineering

Faculty of Marine Technology

Institut Teknologi Sepuluh Nopember

Prepared by :

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DECLARATION OF HONOR

I hereby who signed below declare that :

This bachelor thesis has been written and developed independently without any plagiarism act. All contents and ideas drawn directly from internal and external sources are indicated such as cited sources, literatures and other professional sources.

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Bachelor Thesis Title	:	Activity-Based Fuel Oil Consumption Estimation for Calculating Energy Efficiency Operational Indicator (EEOI) in Indonesian Merchant Ship
Department	:	Marine Engineering

If there is a plagiarism act in the future, i will fully responsible and receive the penalty given by ITS according to the regulation applied.

Surabaya, January 2020

Harris Perdana Kusuma

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Abstract

Global shipping accounts for nearly one million tonnes of CO_2 emissions annually during 2013 – 2015 period, and could grow 50%-250% by 2050 if the condition is unchanged. The International Maritime Organization (IMO) as the specialized agency responded to this issue written in MEPC.304(72) about the strategies of reducing greenhouse gas (GHG) emissions from ships. Energy Efficiency Operational Indicator (EEOI) is a monitoring tool based on CO_2 emissions proposed by IMO written in MEPC.282(70). The objective of this research is to evaluate factors influencing the results of EEOI. Estimation of fuel oil consumption using proposed methods by Bialystocki and Konovessis and Moreno-Gutiérrez, et al. are compared with actual fuel oil consumption resulted in an average error of 20.44% and 15.45%. The EEOI results are 0.000905 ton CO2/TEU-nm for MV Meratus Benoa and 0.000509 ton CO2/TEU-nm for MV Meratus Bontang. Benchmarking process using the same voyage route revealed that MV Meratus Benoa is less efficient than MV Meratus Bontang. MV Meratus Benoa carried less average cargo than MV Meratus Bontang, while having more average fuel oil consumption. Proposed improvement for better EEOI results is improving the cargo management especially for MV Meratus Benoa and evaluation in the ship's operational setting for any specific sea condition.

Keywords: EEOI, Fuel Consumption Estimation Comparison, Shipping Efficiency Benchmarking

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ESTIMASI KONSUMSI BAHAN BAKAR BERBASIS AKTIVITAS UNTUK PERHITUNGAN ENERGY EFFICIENCY OPERATIONAL INDICATOR (EEOI) PADA KAPAL NIAGA INDONESIA

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Abstrak

Aktivitas perkapalan dunia menyumbang hampir satu juta ton emisi CO_2 per tahunnya pada periode 2013 – 2015 dan dapat meningkat sebesar 50% - 250% pada 2050 apabila kondisi tersebut tidak berubah. Sebagai agensi khusus yang menangani masalah maritim, organisasi maritim internasional (IMO) merespon permasalahan tersebut dengan peraturan yang tertuang pada MEPC.304(72) yang berisi strategi untuk mengurangi emisi gas rumah kaca yang berasal dari kapal. *Energy Efficiency Operational Indicator* (EEOI) adalah sebuah sarana untuk memonitor berbasis emisi CO_2 yang diajukan oleh IMO tertulis dalam MEPC.282(70). Tujuan dari penelitian ini adalah untuk mengevaluasi faktor-faktor yang memengaruhi hasil dari EEOI. Estimasi konsumsi bahan bakar menggunakan metode oleh Bialystocki dan Konovessis serta oleh Moreno-Gutiérrez, et al. dikomparasi dengan konsumsi bahan bakar aktual menghasilkan deviasi error dengan rata-rata 20,44% dan 15,45%. Hasil dari rata-rata EEOI MV Meratus Benoa adalah 0,000905 ton CO_2/TEU-nm dan MV Meratus Bontang adalah 0,000509 ton CO_2/TEU-nm. Hasil dari proses *benchmarking* dengan rute yang sama menunjukkan bahwa MV Meratus Benoa memiliki efisiensi yang lebih rendah dibandingkan MV Meratus Bontang. MV Meratus Benoa membawa rata-rata kargo yang lebih sedikit dibandingkan MV Meratus Benoa, selagi memiliki rata-rata konsumsi bahan bakar lebih banyak. Perbaikan yang diusulkan untuk hasil EEOI yang lebih baik adalah peningkatan kualitas dari manajemen kargo khususnya untuk MV Meratus Benoa dan evaluasi pada pengaturan operasional kapal pada beberapa kondisi laut.

Kata Kunci: EEOI, Perbandingan Estimasi Konsumsi Bahan Bakar, Benchmarking Efisiensi Operasional Kapal

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PREFACE

All praise to the Almighty God, for all his blessings, the author can start, work, finish this bachelor thesis.

For the author, this bac helor thesis represents an attempt to contribute to efforts in reducing the global warming. Nowadays, global warming and climate change has become an actual issue that we face. As a human, we need to reconsider our responsibility toward our planet's sustainability, and this thesis is the author's small effort for our better future living and future generation.

This thesis could not be completed without the helps from others. The author would like to acknowledge people who helped and contributed in the process of this bachelor thesis completion, among others:

1. The author's beloved parents, for all their unconditional love, prayers, and supports.
2. Ir. Hari Prastowo, M.Sc. and Dr. Eng. Trika Pitana, S.T., M.Sc. as supervisors that have spent the time giving guidance and direction in this thesis completion.
3. Beny Cahyono, S.T., M.T., Ph. D., as the head of Marine Engineering Department, ITS, Surabaya.
4. Mr. Idi Rambe, Mr. Irwan, and Mr. Steyner as the Fleet Division and Ship Operators of PT. Meratus Line who helped the author to access shipping data.
5. All lecturers of Marine Engineering Department, ITS, Surabaya, Indonesia and Hochschule Wismar, Germany, who give a lot of knowledge and logical thinking in engineering.
6. Sandy Naufal Hisbatullah as the author's college senior for his guidance.
7. Perwira Berliana Fika Adhitama who always give the biggest moral support.
8. Rafli Mahadika Ariapratama, Jefferson Marcel Soadamara, Adhe Tria Pramana, Kevin Surya, Fathin Muhammad, Achdaniel Farikhi, and Purnomo Harlambang who always give advices and supports since the day one.
9. All Marine Engineering Students batch 2016 (Voyage 2016) for all their supports and advices.

The author hopes that by writing of the Final Project Proposal can be useful and provide information to the reader. Because of the limitations of author, constructive criticisms and suggestions are indispensable for perfection in this report.

Surabaya, January 2020

Harris Perdana Kusuma

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CHAPTER I
INTRODUCTION

1.1. Background

Global warming has been a big issue around the world as a result of excessive greenhouse gas (GHG) emission from many industrial and transportation sectors. During the 2013 – 2015 period, emission of CO_2 was reported reaching 924 million tonnes annually during the period as seen in **Figure 1.1.** Although it only 3% of global CO_2 emission, this number is expected to grow 50% - 250% by 2050 if this condition is unchanged (International Maritime Organization, 2014).

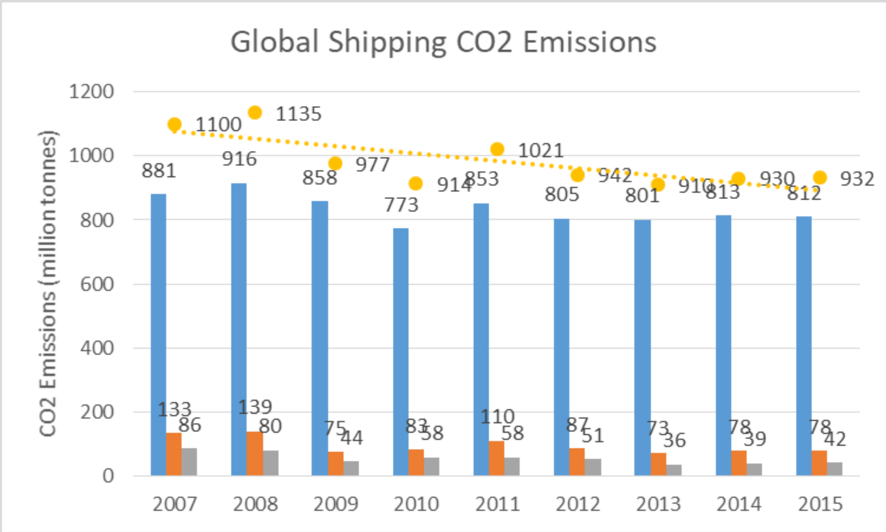

Figure 1. 1 Shipping CO_2 emissions compared to global CO_2 emissions
Source: (Olmer, Comer, Roy, Mao, & Rutherford, 2017)

Energy Efficiency Operational Indicator (EEOI) is a monitoring tool inside the framework of Ship Energy Efficiency Management Plan (SEEMP) as seen in **Figure 1.2** developed by The International Maritime Organization (IMO) to achieve control on GHG emission by ships, particularly in ship's operational life cycle. It is one of many internationally established tool to obtain a quantitative indicator of energy efficiency of a ship or a fleet. IMO voluntarily suggests the use of EEOI as a monitoring tool, but any other monitoring tool apart from EEOI could be used. EEOI measures the ship's energy efficiency explicitly based on CO_2.

The amount of CO_2 emission is the indicator of how efficient a ship utilize energy. It is measured by the mass of CO_2 emitted by a ship or a fleet compared to the amount of work done by the ship, which is expressed by the amount of cargo carried times distance sailed. Not only these 2 factors that influence the EEOI, but fuel oil consumption and type of fuel used are also taken part in the amount of CO_2 emitted.

However, sailing distance is usually a fixed variable in a voyage because a ship's route has been determined during their design stage.

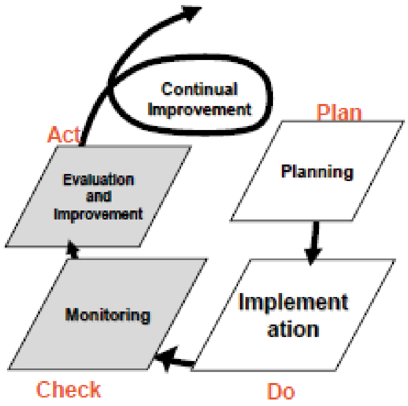

Figure 1. 2 Ship Energy Efficiency Management Plan (SEEMP) Framework

Fuel oil consumption is a significant influence on the result of EEOI. Factors attributed to fuel oil consumption are the ship's speed and engine power. Nonetheless, when a ship is sailing at sea, there are many factors to be responsible for affecting the voyage. Degeneration of weather, increasing draft and displacement, and hull and propeller deteriorating could impact to an increase of resistance (International Maritime Organization, 2014), hence contribute to more fuel consumption.

Approaches and attempts for operating with less fuel oil consumption have been done since a long time ago, and slow steaming is one among them. Slow steaming is an application of slowing speed in order to achieve lower fuel consumption as well as carbon emission (Sanguri, 2012). Nevertheless, slow steaming is limited for improvement, resulting from a safety factor, as the engine is gradually worn out faster when operating on low load.

Estimation of the current ship's fuel consumption is a significant advantage for many shipowners, as data of fuel consumption is more accurate than based on sea trial's result. This estimation could further be used for assessing the ship's energy efficiency with a more reliable data source. Moreover, ship operators could comprehend and attempt a better operational setting which suits the best for their ship.

Amendments to MARPOL Annex VI about data collection system for fuel oil consumption of ships entered into force on 1 March 2018, as adopted by Resolution MEPC.282(70). This amendment requires ships of 5,000 gross tonnages and above to collect consumption data for each of the fuel oil they use. This data then submitted to the flag state and will be given a statement of compliance. Flag states are required to transfer the data into an IMO Ship Fuel

Oil Consumption Database, which is a module inside the Global Integrated Shipping Information System (GISIS).

This integration showed how serious the IMO deal with marine pollution from ships. IMO seeks to achieve a reduction in CO_2 and GHGs emissions by 50% in 2050 compared to 2008. It is more achievable as IMO created the framework of energy-efficient shipping.

Energy-efficient shipping means reducing emission while reducing overall energy consumption. In order to measure a ship's energy efficiency for EEOI, it is initially required to define the current fuel oil consumption. The aim of such analysis could be an accurate estimation of current fuel consumption compared to sea trials, and be a measure of the ship's performance based on CO_2 emission.

1.2. Problem Analysis

Based on the background above, problems that are possible to discuss further are:

1. Which method is more accurate to estimate fuel oil consumption?
2. What factors affect the result of EEOI?
3. What is the ship's current efficiency based on EEOI result?
4. What improvement could possibly be done to save more fuel as well as increasing energy efficiency of the ship based on fuel oil consumption estimation and EEOI result?

1.3. Scopes and Limitations

Scopes and limitations in this bachelor thesis are:

1. Estimation of fuel oil consumption is using methods proposed by (Bialystocki & Konovessis, 2016) and (Moreno-Gutiérrez, et al., 2018)
2. EEOI as monitoring tool within the SEEMP framework is based on CO_2 produced by ship.
3. Monitoring is done in merchant ships particularly container ships.
4. All data is assumed to be correct.

1.4. Objectives

Purposes aimed from this research are:

1. To determine which method is more accurate to estimate fuel oil consumption
2. To evaluate any factors influencing the EEOI results
3. To know the ship's current performance based on EEOI calculation
4. To suggest what could be done to improve the ship's energy efficiency in order to save fuel according to fuel oil consumption estimation and EEOI result?

1.5. Benefits

Benefits of this bachelor thesis are:

1. Fuel oil estimation method could be a base for making an algorithm to calculate EEOI.
2. As a reference for accurately estimating fuel oil consumption.
3. Could be used as a reference for evaluating CO_2 production and energy efficiency of a ship.
4. As a reference for improving the ship's operational efficiency in order to save fuel oil consumption and to reduce CO_2 production of the ship.

1.6. Deliverable

This bachelor thesis proposed methods of estimating fuel oil consumption from (Bialystocki & Konovessis, 2016) and (Moreno-Gutiérrez, et al., 2018) for determining ship's current performance from the calculation result of Energy Efficiency Operational Indicator (EEOI).

CHAPTER II
LITERATURE REVIEW

2.1. Problem Overview

Under Paris agreement, parties of the United Nations Framework Convention on Climate Change (UNFCCC) reached a deal to counter climate change and to speed up and intensify any actions needed to support sustainable low carbon future. The agreement focused on strengthening the global response to the threat of climate change by keeping a global temperature rise this century below 2 degrees Celsius above pre-industrial levels and pursue to limit it to further 1.5 degrees Celsius. The agreement entered into force on 4 November 2016 and Indonesia ratified it at 31 October 2016.

As a specialized agency of the United Nations for safety navigation shipping and marine pollution, the IMO is forced to take a response regarding the Paris agreement. The Marine Environment Protection Committee (MEPC) of IMO amended MARPOL Annex VI to achieve control over GHG emissions from ships. This amendment established regulations on the energy efficiency of ships, a package of technical measures for new ships and operational reduction measures for all ships.

Energy Efficiency Operational Indicator (EEOI) is one among others internationally established monitoring tool of energy efficiency based on CO_2 emission, specifically developed by the IMO inside a framework of Ship Energy Efficiency Management Plan (SEEMP) as a quantitative indicator for international shipping monitoring. Although EEOI is voluntary, but SEEMP is a mandatory regulation from IMO and needs comprehensive trial and understanding to fully benefit from the regulation.

Recently, the data collection system for fuel oil consumption of ships was established by the IMO within the Global Integrated Shipping Information System (GISIS). It is a part of IMO’s step to decline GHG emissions from ships, along with regulations on the energy efficiency of ships. Data collection will further be analyzed to see any possible measures need to be taken.

Fuel oil consumption estimation has been a problem for the shipping industry. To date, ship operators still rely on tank meter or daily measuring to determine fuel oil consumption. No indicator to measure real-time fuel oil consumption is still a big tackle for ship operators to choose the best operation mode for better efficiency. Even though the technology for monitoring real-time fuel oil consumption has been established, it comes with big capital cost for the installation and an added complexity in the ship’s operation.

This combination of fuel oil consumption estimation with energy efficiency indicator (EEOI) would be an excellent indicator for determining the ship’s real-time performance in terms of fuel oil consumption and energy efficiency. It is expected that the calculation could be used as a basis to decide which operation mode has the best efficiency for current energy consumption, and further could reduce the ship's operational cost along with reduced emission produced.

2.2. Ship Engine

Ship's main engine is like the human's heart which is a vital part of ship operation. When the ship is sailing at sea, ship operators have to monitor its performance as it operates non-stop. There used to be only three default layouts for ship propulsion which are direct-coupled diesel engine, diesel engine with gearbox, and steam turbine with gearbox (Taylor, 1990).

Nowadays, marine diesel engines are typically used to propel a ship mainly merchant ships. The diesel engine has some advantages over other kinds of drivers such as higher thermal efficiency compared to gasoline engines and capable of running on residual fuel which is essential since it could consume tons of fuel per day. However, other choices of ship's engine are available for different performance requirements. Gas turbines are used in naval ships to fulfil the need for speed and exceptional reliability. Cruise ships also used gas turbine because of their lack of noise in operation.

Fundamentally, internal combustion engines convert chemical energy inside a fuel which is petroleum-based. Inside the combustion chamber, fuel is combusted into thermal energy and through the expansion of the working fluid, thermal energy is converted to mechanical work as an output (Naber & Johnson, 2014). Theoretically, perfect combustion will create a chemical reaction as follow:

$$\mathbf{C_XH_Y + O_2 \rightarrow CO_2 + H_2O}$$

Nevertheless, since atmospheric air is rather sucked in during combustion than pure O_2, it produced other substances. Nitrogen oxide (NOx) is a substance produced in combustion resulted from high cylinder temperature and pressure. Sulfur oxide (SOx) is created mainly due to the presence of sulfur inside the fuel. Other substances are typically created from imperfect combustion, such as carbon monoxide (CO) and particulate matter (PM).

Conventionally, there are two cycles in internal combustion engine operation, which are two-stroke and four-stroke operational cycle. The number of crankshaft revolution for each power stroke is what differs the cycles. There is one power stroke for one rotation of the crankshaft, while four-stroke needs two rotations of crankshaft for one power stroke, making two-stroke cycle could provide double with the power for the same size engine theoretically (Naber & Johnson, 2014).

2.3. Ship's Air Pollutants

Aside from oily waste, chemicals, sewage and garbage, the exhaust gas is one of many wastes produced by ship. Although it seems that it has no direct effect like an oil spill accident, cumulatively air pollutants will contribute to air quality problems to the environment. Coping with these problems, the International Maritime Organization (IMO) made a new regulation specifically to resolve air pollution from ships.

Regulations to overcome air pollution from ships are written in Annex VI in addition to the International Convention for the Prevention of Pollution from Ships (MARPOL). Annex VI regulates airborne emissions, which is further explained by IMO as any substances that are released into the atmosphere or sea which could create hazards to human health, ecosystems, and marine life. MARPOL Annex VI sets limits on sulfur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances. The annex includes a global cap of 3.5% on the sulfur content of fuel oil from January 1st, 2012 and this will further reduce to 0.5% in January 2020.

a. Carbon Dioxide (CO_2)
   Carbon dioxide is the principal product of combustion of fossil fuels since carbon accounts for 60–90 percent of the mass of fuels that are burned. The carbon dioxide was formed from the fuel which contains carbon and hydrogen elements and reacted with oxygen. Carbon dioxide is non-combustible substance and because of that it is needed to be taken from the combustion chamber.
b. Carbon Monoxide (CO)
   Carbon monoxide, or CO, is a colourless, odourless gas that is formed when carbon in fuel is not burned completely. The reaction occurs when there is a lack of oxygen (O_2) inside the chamber. The highest levels of CO in the outside air typically occur during the colder months of the year when inversion conditions are more frequent. An inversion is an atmospheric condition that occurs when the air pollutants are trapped near the ground beneath a layer of warm air.
c. Oxides of Nitrogen (NO_X)
   This term covers the combinations of nitrogen and oxygen produced as a by-product of the combustion of fuel in the air. The gases produced are predominately nitric oxide (NO) and nitrogen dioxide (NO_2) with traces of other complex chemicals including nitrous oxide (N_2O) and nitrates (NO_3). The amount produced is directly related to the combustion temperature – the greater the peak temperature, the higher the level generated. Although these gases also occur in boiler flue gas, the lower flame temperature results in lower percentages being produced. The high temperatures and pressures that occur in diesel engine cylinders combine to produce relatively high levels of these toxic gases.
   All of these gases combine with water and oxygen in the atmosphere to produce nitrous and nitric acids which are highly corrosive. Nitrogen dioxide is a reddish-brown highly toxic gas which causes lung damage.

At sea level, these gases react with organic compounds to produce low-level ozone (O_3), a significant pollutant and creator of smog. In the upper atmosphere, these same gases, especially NO_2, react to remove ozone. As these gases readily travel great distances from the actual source of production, the impact of the resulting pollution (smog, acid rain etc) can be many miles away from the source.

d. Oxides of Sulfur (SO_X)
Sulfur dioxide, or SO_2, belongs to the family of sulfur oxide gases (SO_x). These gases dissolve easily in water. Sulfur is prevalent in all raw materials, including crude oil, coal, and ores that contain common metals, such as aluminium, copper, zinc, lead, and iron. SO_x gases are formed when fuel containing sulfur, such as coal and oil, is burned, and when gasoline is extracted from oil, or metals are extracted from the ore. SO_2 dissolves in water vapour to form acid and interacts with other gases and particles in the air to form sulfates and other products.

e. Volatile Organic Compounds (VOC) or Hydrocarbons (HC)
VOCs are contained in the lighter fractions released from petrochemical and oil products, including crude oil, during cargo operations and tank cleaning. At sea level, these compounds react with oxides of nitrogen to produce low-level ozone (O3), a significant pollutant and creator of smog. Ozone is a deep lung irritant. VOCs also play a major role in forming other photochemical oxidants which are responsible for numerous chemical and physical atmospheric reactions. Where possible, these should be discharged to shore through the vapour return line. A small unrecoverable amount of vapour will be released from the vessels fuel oil system, especially when heating fuel oil.

f. Particulate Matter (PM)
Particulate matter (PM) is usually divided into two classes based on particle size and comprising soot, ash and unburnt fuel, together with secondary sulphate and nitrate particles. Most of the particles are really lightweight that they are airborne and could be transported to quite a distance. Particles could be reduced by running the engine on a higher grade of distillate fuel, but still could not be eliminated from combustion result.

2.4. Fuel Oil Consumption Estimation Methods

2.4.1. Bialystocki and Konovessis' Method

The method proposed to estimate fuel oil consumption takes into account 4 parameters:

- Ship's draft in the suggested voyage
- Weather force
- Weather direction
- Date of the fore coming voyage

These parameters are used for calculating correction, as seen in the flowchart of the method in **Figure 2.2.**, to obtain fuel consumption. Information regarding these parameters could be gathered from hydrostatic tables and calculation for the ship's draft and weather forecast for weather force and direction.

The data source for the calculation is from the noon report, as seen in **Figure 2.2**, which will be used for the calculation.

To plot the first preliminary curve of fuel consumption, three corrections are applied:

$$\boldsymbol{Fuel\ Cons_{Corr} = 24 \times \frac{Fuel\ Cons_{Recorded}}{Steaming\ Time}} \quad (1)$$

where $Fuel\ Cons_{Recorded}$ and $Steaming\ Time$ is the recorded time and fuel consumption as in **Table 2.3.**

The second correction in the preliminary stage is meant to remove the differences in the ship's draft between each measuring points. The second correction was:

$$\boldsymbol{Fuel\ Cons_{L} = Fuel\ Cons_{Corr} \times (\frac{Displacement_{Load}}{Displacement_{Corr}})^{\frac{2}{3}}} \quad (2)$$

where:

$Fuel\ Cons_{Corr}$: Fuel consumption as corrected in equation 1

$Displacement_{Load}$: Ship's displacement at design draft

$Displacement_{Corr}$: Ship's actual displacement

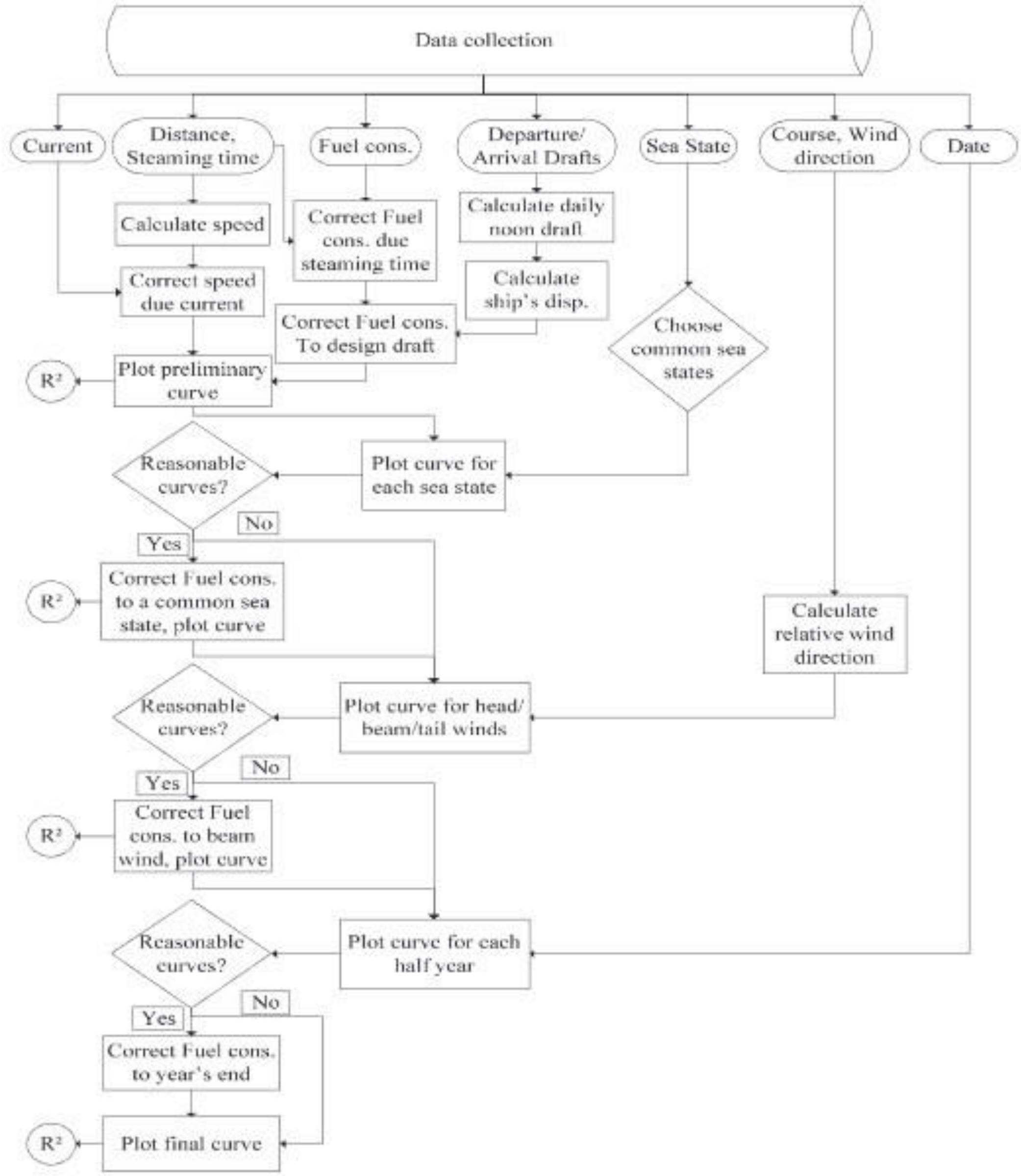

Figure 2. 1 Bialystocki & Konovessis' outline procedure of fuel consumption curve prediction

Final correction in the preliminary stage is to correct the ship's speed over ground by observing current from several voyages. The ship's speed over ground was corrected as follows:

IF Current Direction = Aft → Ship's Speed

= Recorded Speed + Current Speed

IF Current Direction = Fwd → Ship's Speed

= Recorded Speed – Current Speed

IF Current Direction = 0 → Ship's Speed = Recorded Speed

After the preliminary stage of fuel consumption is calculated and the initial curve has been plotted, the next step is to take into account the weather effect. The force of the wind and wind direction are 2 factors that will be analyzed to refer to their effects.

In term of wind force, the Beaufort scale is used wherein (Bialystocki & Konovessis, 2016), sea states 4,5, and 6 typically represent 75% of the time at sea. This sea states could be changed according to data collected in a different ship along its region where it sets sail.

Fuel consumption correction due to Beaufort scale was applied by shifting all the points from sea state 4 and 6 to a common denominator of sea state 5:

$$\boldsymbol{Fuel\ Cons_{L,B5} = Fuel\ Cons_{L} \times \frac{Fuel\ Cons_{B5}}{Fuel\ Cons_{B4/B6}}} \tag{3}$$

where :

$Fuel\ Cons_{L,B5}$	:	Fuel consumption corrected to the design loading condition, and corrected to specific weather condition in sea state 5
$Fuel\ Cons_{L}$	:	Fuel consumption as corrected in equation 2
$Fuel\ Cons_{B5}$	:	Fuel consumption in the average line at sea state 5
$Fuel\ Cons_{B4/B6}$	:	Fuel consumption in the average line at either sea state 4 or 6

This correction is to show the fuel consumption in sea state 5 compared to sea state 4 or sea state 6. This means ship at sea state 4 will increase her fuel consumption when confronting with sea state 5, and the other way around for ship at sea state 6.

The second weather correction is for wind direction which fuel consumption vs. speed curve is plotted for three relative angle sections against the ship course. These 3 angles are:

- Head wind (0-60 degrees)
- Beam wind (60-120 degrees)
- Tail wind (120-180 degrees)

$Fuel\ Consumption_{L,B5}$ is then corrected to the actual wind direction. To bring the same denominator, beam wind will be used in equation as following:

$$\boldsymbol{Fuel\ Cons_{L,B5,BW} = Fuel\ Cons_{L,B5} \times \frac{Fuel\ Cons_{Beam}}{Fuel\ Cons_{Wind}}} \tag{4}$$

where :

$Fuel\ Cons_{L,B5,BW}$	:	Fuel consumption at a designated speed corrected to the design loading condition, corrected to the environmental condition of sea state 5, and to a beam wind direction
$Fuel\ Cons_{L,B5}$	:	Fuel consumption as corrected in equation 3
$Fuel\ Cons_{Beam}$	:	Fuel consumption in the average line for beam wind condition
$Fuel\ Cons_{Wind}$	:	Fuel consumption in the average line at either head wind or tail wind

This final correction compares the beam wind to either head wind or tail wind. The ship should that run with less fuel consumption with the assistance of wind tail will need to increase her fuel consumption if facing with sailing condition with beam wind against the ship course, and the opposite if the ship meets the head wind.

Fuel consumption will be obtained with regression formula from the curve plotted in the preliminary stage and after final correction due to weather condition.

2.4.2. Moreno-Gutiérrez, et al.'s Method

This method is an activity-based method which is objected to being applicable to all types of ship. The main purpose of this method is originally used for calculating emission, but to calculate it, the method needs to accurately calculate the energy consumption. This proposed method uses the (Goldsworthy & Galbally, 2011) method for calculating Emission Factors, the (Jalkanen, et al., 2009) calculation for Specific Fuel Oil Consumption, the (MAN Diesel and Turbo, 2012) model for defining a ship's power and speed relationship, and the IMO method for the calculation of actual main engine power.

This method removes all uncertainties because no AIS data is used and better information have been provided in ship's noon report (daily on-board datasheet). All variables in the equation would be taken from on-board data.

This method needs calculation of ship resistance to determine the propulsive efficiency of the ship to be modified accordingly to this method.

The total resistance of ship in kilo-Newton could be calculated using the original formula from the ITTC 1957 method with some modification proposed by (Kristensen & Lützen, 2012):

$$\boldsymbol{R_T = \frac{1}{2} \cdot C_T \cdot \rho \cdot S \cdot V^2} \quad (5)$$

$$\boldsymbol{C_T = C_F + C_A + C_{AA} + C_R} \quad (6)$$

$$\boldsymbol{C_F = \frac{0.075}{(logR_n - 2)^2}} \quad (7)$$

$$\boldsymbol{C_A = \frac{0.5 \cdot \log(\Delta) - 0.1 \cdot (\log(\Delta))^2}{1000}} \quad (8)$$

and modification for air resistance specifically for container vessels,

$$\boldsymbol{C_{AA} = \frac{0.28 \cdot TEU^{-0.126}}{1000}} \quad (9)$$

and also a modification for residual resistance,

$$\boldsymbol{C_R = C_{R,Diagram} + \Delta C_{R,B/T\neq 2.5} + \Delta C_{R,LCB} + \Delta C_{R,form} + \Delta C_{R,bulb}} \quad (10)$$

and for coefficient block described by (Watson, 1998) as

$$\boldsymbol{C_b = 0.70 + 1/8 \tan^{-1} \frac{(23 - 100F_n)}{4} radians} \quad (11)$$

Where:

R_T	: Total resistance of ship
C_T	: Total resistance coefficient
C_F	: Frictional resistance coefficient
C_A	: Incremental resistance coefficient
C_{AA}	: Air resistance coefficient
C_R	: Residual resistance coefficient
ρ	: Sea water density
S	: Wetted surface area
V	: Ship’s speed
C_b	: Block coefficient
$C_{R,Diagram}$	: Value extracted from Harvald’s curves
$\Delta C_{R,B/T\neq 2.5}$	: Correction of form and B/T that unequal to 2.5
$\Delta C_{R,LCB}$	: Position of LCB
$\Delta C_{R,form}$	: Shape or hull form
$\Delta C_{R,bulb}$	: Bulbous bow shape and size

For the wetted surface area, (Kristensen & Lützen, 2012) proposed a modification of Mumford's original formula for twin-screw ships with open shaft lines and twin rudder.

$$\boldsymbol{S = 1.53 \cdot (\frac{\nabla}{T} \cdot 1.9 \cdot L_{wl} \cdot T)} \qquad (12)$$

Propulsion efficiency is equal to the ratio between the effective (towing) power P_E and the necessary power delivered to the propeller P_D (MAN Diesel and Turbo, 2012):

$$\boldsymbol{\eta_D = \frac{P_E}{P_D}} \qquad (13)$$

$$\boldsymbol{P_E = R_T \cdot V} \qquad (14)$$

$$\boldsymbol{P_T = \frac{P_E}{\eta_H}} \qquad (15)$$

$$\boldsymbol{P_D = \frac{P_T}{\eta_R \cdot \eta_O}} \qquad (16)$$

where:

P_E : Effective towing power (kN)
P_D : Power delivered to the propeller (kN)
P_T : Thrust power delivered by the propeller to water
η_D : Propulsive efficiency
η_H : Hull efficiency (0.95 to 1.05 for ships with two propellers)
η_R : Relative rotative efficiency (0.98)
η_O : Open water efficiency (0.35 to 0.75)

(Moreno-Gutiérrez, et al., 2018) proposed modification by (International Maritime Organization, 2014) to the propulsive efficiency due to weather condition against the ship and fouling of the ship's hull. A value of 9% is subtracted from the propulsive efficiency due to hull fouling and 10% due to the impact of weather.

$$\boldsymbol{\eta_f = \eta_D - 9\%} \qquad (17)$$

$$\boldsymbol{\eta_w = \eta_D - 10\%} \qquad (18)$$

The general equation for calculating the Main Engine Load factor is

$$\boldsymbol{LF = \frac{P_{transient}}{P_1}} \qquad (19)$$

where:

P_1 : Power at 100% MCR from onboard test
V_1 : Speed at 100% MCR from onboard test
$P_{transient}$: Instantaneous power for calculation

$V_{transient}$: Actual ship speed

Power that propulsion engines have to develop does not depend solely on speed, in addition to transient speed there are other factors that affect the power that these engines must develop to achieve the speed. Furthermore, there are other factors that influence both fuel consumption and emission produced. These factors are those that increase the ship's resistance to movement through the water, i.e. the following three factors:

- Worsening of weather conditions
- Increased draft and displacement
- Worsening of hull and propeller roughness (fouling condition)

Then, to consider those factors, (International Maritime Organization, 2014) proposed this equation for the calculation of power transient of main engines as follow:

$$\boldsymbol{P_{transient}} = \frac{\boldsymbol{P_1}\left(\frac{\boldsymbol{t_{transient}}}{\boldsymbol{t_1}}\right)^{\left(\frac{2}{3}\right)}\left(\frac{\boldsymbol{V_{transient}}}{\boldsymbol{V_1}}\right)^{\boldsymbol{n}}}{\boldsymbol{\eta_w \eta_f}} \tag{20}$$

where:

t_t : Draft at the time

t_1 : Draft at 100% MCR from onboard test

η_w : Modification of propulsion efficiency due to weather

η_f : Modification of propulsion efficiency due to fouling

$2/3$: Assumption of power is related to displacement (Admiralty formula)

n : Constant ship speed coefficient (Speed and power relationship)
4.00 for large, high-speed ships i.e.: container vessels
3.50 for medium-sized, medium-speed ships i.e.: feeder container ships, Ro-Ro, etc.
3.20 for low-speed ships i.e.: tankers and bulk carriers

Energy consumption then calculated using the equation:

$$\boldsymbol{SFOC = SFOC_{relative} \times SFOC_{base}} \tag{21}$$

$$\boldsymbol{SFOC_{relative} = 0.455LF^2 - 0.71LF + 1.28} \tag{22}$$

where:

LF : Load factor, a value from 0 to 1

SFOC : Specific fuel oil consumption

$SFOC_{base}$: From design guide

2.5. Energy Efficiency Operational Indicator (EEOI)

The Energy Efficiency Operational Indicator (EEOI) is a monitoring tool for managing ship and fleet efficiency performance over time. EEOI is a tool developed by MEPC as a part of the Ship Energy Efficiency Management Plan (SEEMP).

Ship Energy Efficiency Management Plan is an operational measure to create a mechanism to improve the ship's energy efficiency. Even though it is voluntarily, the approach of applying SEEMP into a ship or fleet could assist ship owners, ship operators, and other parties which are concerned in the evaluation of the performance of their ship or fleet (The International Maritime Organization, 2016). SEEMP is designed to be implemented for all ships.

Monitoring is a part of the SEEMP framework which is done quantitatively. This value is determined using a calculation. EEOI is developed in purpose for making international standard for energy efficiency calculation, which EEOI could be considered as a primary tool for monitoring. IMO considers other quantitative measures aside from EEOI may be appropriate too.

The EEOI calculation was based on guidelines for voluntary use of the ship's Energy Efficiency Operational Indicator (EEOI). Detailed from the formula given by (Marine Environment Protection Committee, 2016), EEOI is defined as the ratio of the mass of CO_2 emitted per unit of transport work: (Marine Environment Protection Committee, 2009)

$$\boldsymbol{EEOI = \frac{\Sigma_j FC_j \times C_{Fj}}{m_{cargo} \times D}} \tag{23}$$

$$\boldsymbol{Average\ EEOI = \frac{\Sigma_i \Sigma_j \times (FC_{ij} \times C_{Fj})}{\Sigma_i (m_{cargo} \times D)}} \tag{24}$$

where:

j	: fuel type
i	: voyage number
FC_{ij}	: the mass of consumed fuel j at voyage i
C_{Fj}	: fuel mass to CO_2 conversion factor of fuel j
m_{cargo}	: cargo carried, or work done (tonnes, TEU, passengers) or gross tonnage of passenger ships
D	: distance travelled

2.6. Fuel Oil to CO_2 Conversion Factor

Calculation of CO_2 as a product of fuel combustion is done using an approaching method. However, each type of fuels has a specific carbon chain and other chemical properties. The conversion factor is used to determine the amount of CO_2 released from combustion for a specific volume of fuel oil burned. Fuel mass to CO_2 mass conversion factors (C_F) is released by IMO in the guidelines of EEOI, with value as follow:

Table 2. 1 CO_2 Mass Conversion Factors (C_F)
Source: MEPC.1/Circ.684, 2009

Type of Fuel	Reference	Carbon content	C_F (ton-CO_2/ton-fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil	ISO 8217 Grades RMA through RMD	0.860	3.151040
3. Heavy Fuel Oil	ISO 8217 Grades RME through RMK	0.850	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.750	2.750000

Effectively started from 1 September 2018, Indonesian government mandatorily pushed the usage of B20 program. B20 is a mixture of 20% biodiesel and 80% of diesel fuel. Biodiesel is a biofuel in the form of fatty acid methyl ester (FAME) made from vegetable oil. Indonesia, as a large producer of crude palm oil (CPO), utilizes it to overcome the abundance. B20 has also been proven to have less CO emission from high cetane number and high oxygen content.

Table 2. 2 Emission Coefficient in (gram/liter)
Source: (Wijono, 2017)

B-XX	SO_2	NO_X	HC	PM	CO	CO_2
B0	16.119	9.292	11.125	2.383	36.852	2,013.025
B5	15.360	9.292	10.619	2.351	35.651	1,959.739
B10	14.475	9.229	9.924	2.301	34.513	1,900.533
B15	13.780	9.166	9.418	2.174	33.375	1,876.850
B20	12.895	9.102	8.913	2.054	32.364	1,847.247
B30	11.315	9.039	8.091	1.947	29.583	1,758.437
B50	8.091	8.850	6.384	1.726	24.083	1,586.738
B100		8.407	3.603	1.315	19.090	1,385.435

2.7. Automatic Identification System (AIS)

The Automatic Identification System (AIS) is an automated, autonomous tracking system which is extensively used in the maritime world for the exchange of navigational information between AIS-equipped terminals. AIS is installed onboard the ship as well as coastal Vessel Traffic Service (VTS) systems to monitor vessel movements around the world.

The International Maritime Organization (IMO) originally developed AIS as a standard that would help vessels avoid collisions and help port authorities to control marine traffic more efficiently. As a result of the relative mandate from SOLAS 2002, from December 2004, IMO requires all passengers vessels as well as commercial vessels over 299 gross tonnages (GT) that sail internationally to carry class A AIS transponder that transmits and receives AIS data.

AIS works using GPS that collects the subject vessel's position and movement details, as well as dynamic and static information regarding the vessel's feature such as draft and type of cargo. Those details are automatically broadcasted at regular intervals.

2.8. Ship's Noon Report

A noon report is a data sheet prepared by the ship's chief engineer on a daily basis. The report provides the vessel's position and other relevant standardized data to assess the performance of the ship based on its speed and environmental forces including weather conditions.

The chief engineer is responsible for preparing the noon report and it is sent by the master to the company and shore management at a fixed time on a daily basis. It is normally sent during noon, hence the name is called noon report.

```
NOON REPORT AT SEA
MBT/V.1901 N/ ID SRG-PNK
1. Date / Time : 10.01.2019/12:00 LT
2. Port of-to : Semarang - Pontianak
3. Lat / Long : 06-06.10 S / 110-04.93 E
4. Course : 337°
5. St. time :06 Hrs 18 Min
6. Distance : 52 Nm
7. Avg. Speed : 8.25 kts
8. Tot. St. time : 06 Hrs 18 Min
9. Tot. Dist : 52 Nm
10. Tot. Avg. Speed : 8.25 kts
11. Dist. to go :397.5 Nm
12. Wind / Sea : NW 2 / Smooth Sea
13. Weather : C
14. Draft : F : .4.10 M / A : 4.30 M
15. Rpm : 630 (SS)
16. MFO ROB : 75.398 Ltr / Cons ME : 440 Ltr
MDO ROB : 50.149 Ltr / Cons ME : 1.452 Ltr / Cons AE : 315 Ltr
LO ME ROB/Cons : 1.630 Ltr / Cons : - Ltr
LO AE ROB/Cons : 1.065 Ltr / Cons : - Ltr
LO Hyd ROB/Cons : 3430 Ltr/ Cons : 0 Ltr
Boil : OFF
```

Figure 2. 2 Ship's Noon Report
Source: Author's Document

2.9. Ship's Departure Report

Departure report is an internal document of the company that is sent by the ship's master to the shipping company. The departure report contains information about the ship's activities in the port, among others are the time when the ship commenced loading or unloading, how many cargo loaded or unloaded, fuel remains on board, draft condition, and any other specific port activities technical information.

DEPARTURE KUMAI: 25/03/2019

MBN/ Voy.1910S/ PKX-SRG/ 2019

1. Commenced Discharge : 24.03.2019 - 20.00LT
2. Completed Discharge : 25.03.2019 - 04.06LT
3. Cargo Discharge : 190 Boxes/ 194 Teus= 3817 Tons
4. Commenced Loading : 25.03.2019 - 04.00LT
5. Completed Loading : 25.03.2019 - 21.06LT
6. Cargo Loading : PKX-SRG: 152 Boxes/ 152 Teus (102TF,50TE)
   PKX-SUB: 52 Boxes/ 60 Teus (44TE,8FE)
7. COB : 204 Boxes/ 212 Teus= 2503 Tons
8. GM : 5.08 M
9. Minimum GM : 2.60 M
10. Draft FWD / AFT : FWD= 2.80 M/ Aft= 4.40 M

Figure 2. 3 Ship's Departure Report
Source: Author's Document

CHAPTER III
METHODOLOGY

3.1. Flowchart

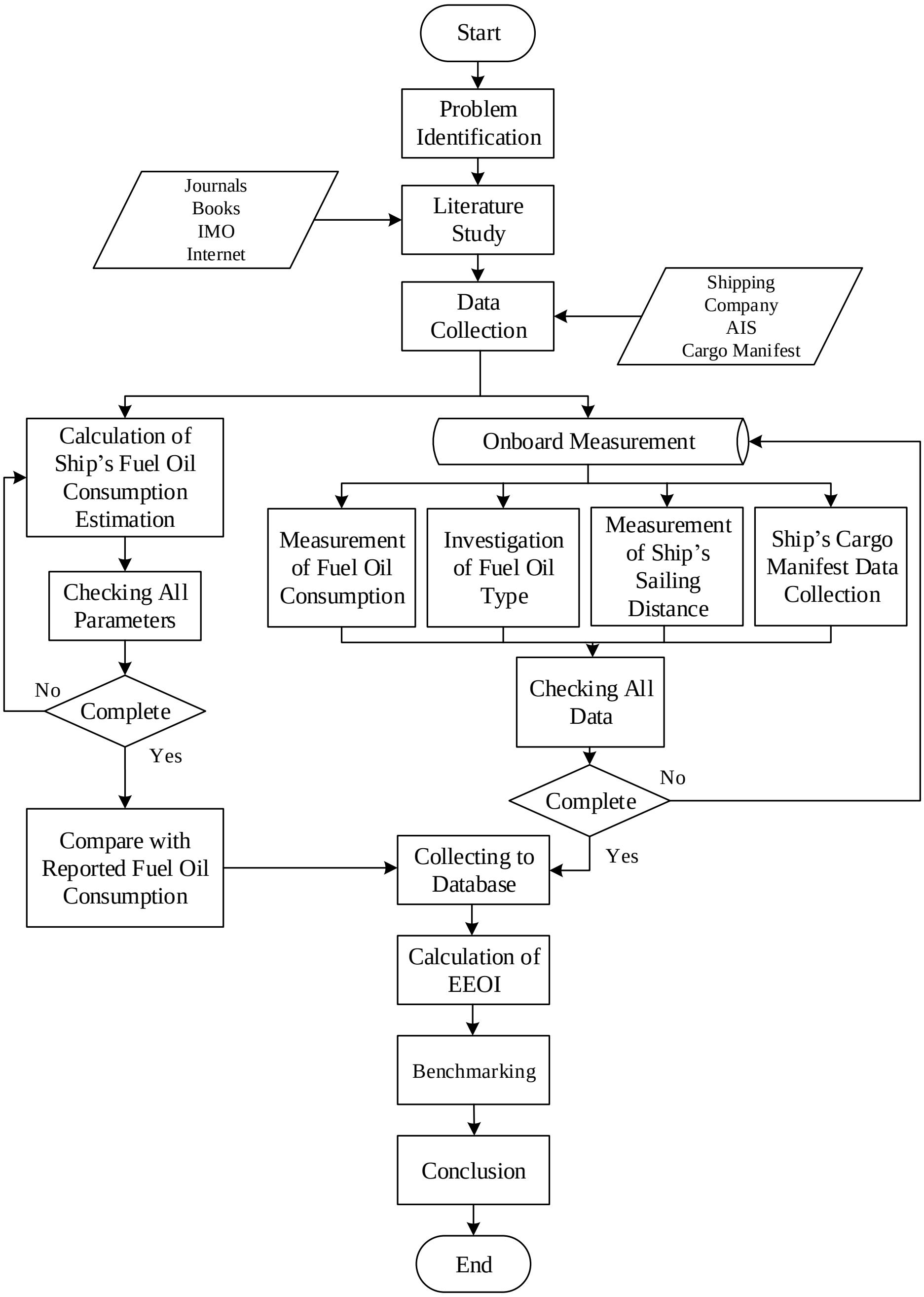

Figure 3. 1 Research flowchart

3.2. Explanation of Methodology Flowchart

3.2.1. Problem Identification

Problem identification is the first step in writing this thesis. Research questions are obtained through problem identification. The main problem comes from the existing condition compared to the required state by regulation. In this stage, problems are specifically identified in order to determine the specific objectives of this thesis. Therefore, the purpose of this thesis could be acknowledged.

3.2.2. Literature Study

After problems are identified, the literature study needs to be done in order to obtain information as a scientific base and to support the analysis of the research. The literature study is done by extensively reading journals, IMO regulations, books, and website.

3.2.3. Collecting Data

Then, after literature study is done, data for this research needs to be collected. Data collection is done by gathering information from the ship's operational data. Then, it will be used for estimating fuel consumption and for calculating the EEOI in order to obtain its energy efficiency.

a. Fuel Oil Consumption Measurement
Fuel oil consumption presents the amount of fuel oil consumed to achieve the ship's operational demands. Data of fuel oil consumption is planned to be collected from the shipping company.

b. Fuel Oil Type Investigation
Fuel oil type presents the fuel used in the combustion process onboard the ships. Fuel oil type is needed for determining the amount CO_2 produced from fuel oil combustion. Data of fuel oil type is planned to be collected from the shipping company or from other sources.

c. Ship's Sailing Distance Measurement
Ship's sailing distance presents the amount of work done by the ship. Sailing distance is planned to be collected from the Automatic Identification System (AIS).

d. Ship's Cargo Manifest Data Collection
Ship's cargo manifest presents the number of goods transported by the ship. It is then could be calculated to obtain the efficiency of the ship. Ship's cargo manifest data is planned to be collected from the shipping company or from other sources.

e. Calculation of Ship Fuel Oil Consumption Estimation
The calculation is done using two methods to estimate the fuel oil consumption. Data needed for the calculations are collected from ship's noon report, weather forecast, or other sources.

3.2.4. Data Checking

Data obtained from data collection is then be checked to ensure all data needed for the calculations are complete. All data must be checked to ensure that all calculations could be completed using data collected.

3.2.5. Comparing with Reported Fuel Oil Consumption

Results of fuel oil estimation obtained from the calculation of the two methods then compared with reported fuel oil consumption obtained from the ship's operational data. Errors of each method are calculated and ranked based on its accuracy to the reported data.

3.2.6. Collecting to Database

Data and results of the calculation are collected into the database. All data will be mapped based on the window time as a requirement for calculation of EEOI.

3.2.7. Calculation of EEOI

Calculation of EEOI using all data from the database to achieve the ship's operational indicator. In this stage, the ship's operational efficiency could be determined. EEOI calculation will be done using the software.

3.2.8. Benchmarking

Benchmarking is the process to assess and evaluate the sister ship using EEOI. The result of benchmarking then compared between the two ships. The benchmarking result will be evaluated in order to determine any opportunity to increase the ship's energy efficiency for the shipping company.

3.2.9. Conclusion

At this stage of writing, conclusions and suggestions are carried out as the purpose of this thesis.

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CHAPTER IV
DATA ANALYSIS

4.1. Data Collection

Data is collected to do the calculations needed for the completion of this research. Data is collected from various sources, among others are from the shipping company, AIS database, and journal literature.

4.1.1. Ship Particular

This research is conducted in two ships. Detailed information about these ships could be obtained from the company's internal documents.

Table 4. 1 MV Meratus Benoa Ship Particular
Source: PT Meratus Line Shipping Company

General		
Vessel Name	MV Meratus Benoa	
Type of Vessel	Container Ship	
Owner	PT. Meratus Line	
Flag	Indonesia	
IMO-Number	9509231	
MMSI	525025061	
GRT	3668	GT
Summer DWT	5161	Ton
Summer Displacement	7561	Ton
LOA	107.68	Meter
LPP	99.09	Meter
Breadth Moulded	20.6	Meter
Depth Moulded	6	Meter
Summer Draft	4.2	Meter
Speed	10	Knot
Classification	NK/BKI	
Machinery		
Main Engine	Yanmar 6EY26 - 2 x 1920 kW/750 RPM	
Propeller	Fixed; 4 blades; 2 x 2.7 m; Pitch 0.61 m	
Auxiliary Engine	HND MWM Henan Diesel 4 x TBD 234 V8 371 HP	

Table 4. 2 MV Meratus Bontang Ship Particular
Source: PT Meratus Line Shipping Company

General		
Vessel Name	MV Meratus Bontang	
Type of Vessel	Container Ship	
Owner	PT. Meratus Line	
Flag	Indonesia	
IMO-Number	9569865	
MMSI	525025059	
GRT	3668	GT
Summer DWT	5161	Ton
Summer Displacement	7561	Ton
LOA	107.68	Meter
LPP	99.11	Meter
Breadth Moulded	20.6	Meter
Depth Moulded	5.8	Meter
Summer Draft	4.215	Meter
Speed	10	Knot
Classification	NK/BKI	
Machinery		
Main Engine	Yanmar 6EY26 - 2 x 920 kW/750 RPM	
Propeller	Fixed; 4 blades; 2 x 2.7 m; Pitch 0.61 m	
Auxiliary Engine	HND MWM Henan Diesel 4 x TBD 234 V8 371 HP	

4.1.2. Window Time

Window time is a representation of the ship's operating time on a trip. Window time in a trip begins when the ship commenced loading operation in origin port and completed discharge operation in the destination port. The data was obtained from the ship departure report. The trip number indicates a trip in a route. The trip number is developed by the author to ease the grouping of voyages.

Table 4. 3 MV Meratus Benoa Window Time
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Window Time	
		Origin	Destination	Departure	Arrival
1901	MBN-1	Surabaya	Kumai	06/01/2019 20:18:00	11/01/2019 9:48:00
	MBN-2	Kumai	Semarang	11/01/2019 9:36:00	14/02/2019 2:30:00
	MBN-3	Semarang	Surabaya	14/01/2019 2:12:00	16/01/2019 12:00:00
1902	MBN-4	Surabaya	Samarinda	16/01/2019 16:54:00	21/01/2019 8:48:00
	MBN-5	Samarinda	Surabaya	21/01/2019 8:54:00	25/01/2019 20:06:00
1903	MBN-6	Surabaya	Kumai	26/01/2019 14:00:00	30/01/2019 5:24:00
	MBN-7	Kumai	Semarang	30/01/2019 3:00:00	02/02/2019 10:12:00
	MBN-8	Semarang	Surabaya	02/02/2019 10:18:00	03/02/2019 1:30:00
1904	MBN-9	Surabaya	Sampit	04/02/2019 10:42:00	07/02/2019 8:48:00
	MBN-10	Sampit	Surabaya	07/02/2019 9:00:00	09/02/2019 20:00:00
1905	MBN-11	Surabaya	Semarang	10/02/2019 9:00:00	12/02/2019 5:18:00
	MBN-12	Semarang	Kumai	12/02/2019 5:24:00	14/02/2019 4:42:00
	MBN-13	Kumai	Surabaya	14/02/2019 5:00:00	16/02/2019 22:42:00
1906	MBN-14	Surabaya	Kumai	16/02/2019 21:00:00	20/02/2019 4:42:00
	MBN-15	Kumai	Surabaya	20/02/2019 3:36:00	22/02/2019 1:48:00
1907	MBN-16	Surabaya	Kumai	22/02/2019 22:18:00	26/02/2019 9:12:00

Voyage Number	Trip Number	Route		Window Time	
		Origin	Destination	Departure	Arrival
1907	MBN-17	Kumai	Surabaya	26/02/2019 2:00:00	02/03/2019 17:00:00
1908	MBN-18	Surabaya	Kumai	02/03/2019 14:06:00	05/03/2019 2:42:00
	MBN-19	Kumai	Semarang	05/03/2019 20:00:00	08/03/2019 23:30:00
	MBN-20	Semarang	Surabaya	08/03/2019 23:48:00	12/03/2019 1:36:00
1909	MBN-21	Surabaya	Kumai	12/03/2019 1:42:00	15/03/2019 9:30:00
	MBN-22	Kumai	Semarang	15/03/2019 9:48:00	18/03/2019 7:48:00
	MBN-23	Semarang	Surabaya	18/03/2019 8:30:00	21/03/2019 22:00:00
1910	MBN-24	Surabaya	Kumai	21/03/2019 21:00:00	25/03/2019 22:00:00
	MBN-25	Kumai	Semarang	25/03/2019 4:00:00	27/03/2019 22:30:00
	MBN-26	Semarang	Surabaya	27/03/2019 0:24:00	30/03/2019 17:46:00

Table 4. 4 MV Meratus Bontang Window Time
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Window Time	
		Origin	Destination	Departure	Arrival
1901	MBT-1	Semarang	Pontianak	09/01/2019 22:30:00	13/01/2019 23:48:00
	MBT-2	Pontianak	Semarang	13/01/2019 21:54:00	18/01/2019 8:30:00
1902	MBT-3	Semarang	Pontianak	18/01/2019 8:36:00	21/01/2019 20:24:00

Voyage Number	Trip Number	Route		Window Time	
		Origin	Destination	Departure	Arrival
1902	MBT-4	Pontianak	Semarang	21/01/2019 16:00:00	26/01/2019 16:28:00
1903	MBT-5	Semarang	Pontianak	26/01/2019 16:48:00	30/01/2019 1:00:00
	MBT-6	Pontianak	Surabaya	29/01/2019 20:48:00	02/02/2019 17:00:00
1904	MBT-7	Surabaya	Sampit	03/02/2019 18:18:00	06/02/2019 0:00:00
	MBT-8	Sampit	Surabaya	06/02/2019 13:24:00	09/02/2019 1:00:00
1905	MBT-9	Surabaya	Kumai	09/02/2019 9:00:00	12/02/2019 17:12:00
	MBT-10	Kumai	Semarang	12/02/2019 17:36:00	15/02/2019 14:24:00
	MBT-11	Semarang	Surabaya	15/02/2019 9:36:00	17/02/2019 14:42:00
1906	MBT-12	Surabaya	Sampit	17/02/2019 18:42:00	20/02/2019 3:54:00
	MBT-13	Sampit	Surabaya	20/02/2019 4:00:00	22/02/2019 9:24:00
1907	MBT-14	Surabaya	Sampit	22/02/2019 9:18:00	26/02/2019 0:12:00
	MBT-15	Sampit	Surabaya	25/02/2019 20:24:00	28/02/2019 1:12:00
1908	MBT-16	Surabaya	Kumai	28/02/2019 9:30:00	03/03/2019 16:42:00
	MBT-17	Kumai	Surabaya	03/03/2019 16:48:00	06/03/2019 13:12:00
1909	MBT-18	Surabaya	Semarang	06/03/2019 13:24:00	08/03/2019 7:18:00
	MBT-19	Semarang	Kumai	08/03/2019 7:24:00	10/03/2019 11:24:00

Voyage Number	Trip Number	Route		Window Time	
		Origin	Destination	Departure	Arrival
1909	MBT-20	Kumai	Surabaya	10/03/2019 11:30:00	14/03/2019 7:18:00
1910	MBT-21	Surabaya	Semarang	15/03/2019 2:00:00	17/03/2019 9:18:00
	MBT-22	Semarang	Kumai	17/03/2019 9:24:00	19/03/2019 19:54:00
	MBT-23	Kumai	Surabaya	19/03/2019 20:06:00	23/03/2019 3:12:00

4.1.3. Reported Fuel Oil Consumption

The ship's reported fuel oil consumption data is obtained from the shipping company's internal documents, specifically named "bunker report". The bunker report contains some information, such as voyage number, steaming time, amount of fuel consumed in operation mode, type of fuel, and amount of fuel remaining on the fuel tank.

Table 4. 5 Reported Fuel Oil Consumption of MV Meratus Benoa
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Fuel Oil Consumption (Liter)					
		Main Engine		Auxiliary Engine		Total	
		MFO	HSD	HSD		MFO	HSD
		At Sea	At Port*	At Port	At Sea		
1901	MBN-1	6,915	2,520	5,233	1,886	6,915	9,639
	MBN-2	7,300	3,400	5,177	1,928	7,300	10,505
	MBN-3	5,134	1,900	797	1,147	5,134	3,844
1902	MBN-4	13,795	4,360	4,010	3,528	13,795	11,898
	MBN-5	23,028	6,600	3,881	3,740	23,028	14,221
1903	MBN-6	13,041	5,520	4,809	2,508	13,041	12,837
	MBN-7	7,988	3,720	4,013	1,959	7,988	9,692
	MBN-8	4,240	920	1,048	1,186	4,240	3,154
1904	MBN-9	11,047	4,520	3,288	1,612	11,047	9,420
	MBN-10	6,944	5,080	2,134	2,135	6,944	9,349
1905	MBN-11	5,150	5,640	4,223	1,278	5,150	11,141

Voyage Number	Trip Number	Fuel Oil Consumption (Liter)					
		Main Engine		Auxiliary Engine		Total	
		MFO	HSD	HSD	MFO	MFO	HSD
		At Sea	At Port*	At Port	At Sea		
1905	MBN-12	7,797	1,120	495	1,629	7,797	3,244
	MBN-13	6,553	3,560	3,577	1,690	6,553	8,827
1906	MBN-14	7,540	2,850	2,862	2,110	7,540	7,822
	MBN-15	6,694	4,890	3,839	1,754	6,694	10,483
1907	MBN-16	8,206	2,830	3,355	1,988	8,206	8,173
	MBN-17	6,864	3,480	3,809	1,992	6,864	9,281
1908	MBN-18	9,261	3,160	5,833	1,791	9,261	10,784
	MBN-19	11,894	3,680	4,762	1,778	11,894	10,220
	MBN-20	4,554	1,640	1,595	1,060	4,554	4,295
1909	MBN-21	12,194	3,490	5,522	1,500	12,194	10,512
	MBN-22	11,561	3,704	4,075	1,662	11,561	9,441
	MBN-23	4,534	2,028	1,356	1,120	4,534	4,504
1910	MBN-24	10,571	3,796	6,725	1,970	10,571	12,491
	MBN-25	8,139	3,150	3,030	2,264	8,139	8,444
	MBN-26	4,416	1,594	1,138	1,074	4,416	3,806

*for manoeuvring

Table 4. 6 Reported Fuel Oil Consumption of MV Meratus Bontang
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Fuel Oil Consumption (Liter)					
		Main Engine		Auxiliary Engine		Total	
		MFO	HSD	HSD		MFO	HSD
		At Sea	At Port*	At Port	At Sea		
1901	MBT-1	11,968	2,518	6,382	2,720	11,968	11,620
	MBT-2	10,406	3,221	2,767	2,365	10,406	8,353
1902	MBT-3	12,688	2,054	2,695	2,810	12,688	7,559
	MBT-4	9,900	2,694	1,953	2,250	9,900	6,897
1903	MBT-5	17,694	3,340	2,493	2,495	17,694	8,328
	MBT-6	11,704	2,666	1,840	2,660	11,704	7,166
1904	MBT-7	6,160	3,966	3,878	1,400	6,160	9,244
	MBT-8	5,390	3,286	2,020	1,225	5,390	6,531
1905	MBT-9	6,644	1,888	3,450	1,765	6,644	7,103

Voyage Number	Trip Number	Fuel Oil Consumption (Liter)					
		Main Engine		Auxiliary Engine		Total	
		MFO	HSD	HSD	MFO	MFO	HSD
		At Sea	At Port*	At Port	At Sea		
1905	MBT-10	6,512	3,820	3,947	1,480	6,512	9,247
	MBT-11	3,410	2,396	1,155	775	3,410	4,326
1906	MBT-12	5,940	4,898	2,710	1,350	5,940	8,958
	MBT-13	5,148	4,170	2,237	1,170	5,148	7,577
1907	MBT-14	4,246	4,740	1,995	966	4,246	7,701
	MBT-15	5,280	4,040	3,288	1,200	5,280	8,528
1908	MBT-16	6,820	4,140	3,405	1,550	6,820	9,095
	MBT-17	5,390	4,592	3,100	1,230	5,390	8,922
1909	MBT-18	4,422	3,478	2,520	1,005	4,422	7,003
	MBT-19	5,368	2,406	968	1,230	5,368	4,604
	MBT-20	5,060	4,000	2,595	1,150	5,060	7,745
1910	MBT-21	5,280	7,096	6,355	600	5,280	14,051
	MBT-22	6,006	1,528	670	1,415	6,006	3,613
	MBT-23	6,028	3,680	3,367	1,370	6,028	8,417

*for manoeuvring

4.1.4. Cargo Carried

Cargo carried is the amount of cargo, in the form of TEU, carried in a trip. Information regarding the amount of cargo carried could be obtained from the shipping company internal documents, particularly from the ship's departure report.

Table 4. 7 Cargo Carried per trip by MV Meratus Benoa
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Cargo Carried								
		20' FT				40' FT				TEUs
		Full	Empty	Reefer	Total	Full	Empty	Reefer	Total	Total
1901	MBN-1	146	0	0	146	8	0	0	8	162
	MBN-2	129	65	0	194	0	2	0	2	198
	MBN-3	5	138	0	143	0	2	0	2	147
1902	MBN-4	163	0	0	163	0	12	0	12	187
	MBN-5	112	60	0	172	2	3	0	5	182
1903	MBN-6	207	0	0	207	7	0	0	7	221
	MBN-7	178	82	0	260	0	4	0	4	268

Voyage Number	Trip Number	Cargo Carried								
		20' FT				40' FT				TEUs
		Full	Empty	Reefer	Total	Full	Empty	Reefer	Total	Total
1903	MBN-8	10	153	0	163	0	0	0	0	163
1904	MBN-9	193	0	0	193	11	0	0	11	215
	MBN-10	1	77	0	78	0	17	0	17	112
1905	MBN-11	164	0	0	164	7	0	0	7	178
	MBN-12	201	0	0	201	10	0	0	10	221
	MBN-13	99	57	0	156	0	9	0	9	174
1906	MBN-14	198	0	0	198	0	4	0	4	206
	MBN-15	52	143	0	195	1	22	0	23	241
1907	MBN-16	206	0	1	207	3	0	0	3	213
	MBN-17	124	123	0	247	1	2	0	3	253
1908	MBN-18	197	0	0	197	10	0	0	10	217
	MBN-19	177	61	0	238	0	5	0	5	248
	MBN-20	23	12	0	35	0	1	0	1	37
1909	MBN-21	209	0	0	209	3	0	0	3	215
	MBN-22	123	115	0	238	0	11	0	11	260
	MBN-23	31	64	0	95	0	11	0	11	117
1910	MBN-24	186	0	0	186	4	0	0	4	194
	MBN-25	102	94	0	196	0	8	0	8	212
	MBN-26	3	74	0	77	0	8	0	8	93

Table 4. 8 Cargo Carried per trip by MV Meratus Bontang
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Cargo Carried								
		20' FT				40' FT				TEUs
		Full	Empty	Reefer	Total	Full	Empty	Reefer	Total	Total
1901	MBT-1	159	0	0	159	17	0	0	17	193
	MBT-2	30	134	0	164	0	12	1	13	190
1902	MBT-3	130	0	0	130	18	0	0	18	166
	MBT-4	9	148	0	157	0	18	1	19	195
1903	MBT-5	106	0	0	106	12	0	0	12	130
	MBT-6	39	88	0	127	0	18	0	18	163
1904	MBT-7	190	0	0	190	19	0	0	19	228

Voyage Number	Trip Number	Cargo Carried								
		20' FT				40' FT				TEUs
		Full	Empty	Reefer	Total	Full	Empty	Reefer	Total	Total
1905	MBT-9	197	0	2	199	19	0	0	19	237
	MBT-10	128	111	0	239	0	8	0	8	255
	MBT-11	62	185	0	247	0	0	0	0	247
1906	MBT-12	222	55	0	277	16	0	0	16	309
	MBT-13	47	271	0	318	0	16	0	16	350
1907	MBT-14	232	55	0	287	11	0	0	11	309
	MBT-15	38	269	0	307	0	17	0	17	341
1908	MBT-16	237	55	0	292	6	0	0	6	304
	MBT-17	69	143	0	212	0	4	0	4	220
1909	MBT-18	194	55	0	249	3	0	0	3	255
	MBT-19	230	55	0	285	3	0	0	3	291
	MBT-20	126	135	0	261	6	4	0	10	281
1910	MBT-21	206	55	0	261	15	0	0	15	291
	MBT-22	263	55	0	318	23	0	0	23	364
	MBT-23	271	159	0	430	15	2	0	17	464

4.1.5. Distance Sailed

Data of distance sailed by MV Meratus Benoa and MV Meratus Bontang is obtained from the processed data from the Automatic Identification System (AIS).

Table 4. 9 Distance Sailed by MV Meratus Benoa
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Distance Sailed	
		Origin	Destination	km	nm
1901	MBN-1	Surabaya	Kumai	547.233	295.482
	MBN-2	Kumai	Semarang	503.617	271.932
	MBN-3	Semarang	Surabaya	357.714	193.150
1902	MBN-4	Surabaya	Samarinda	967.142	522.215
	MBN-5	Samarinda	Surabaya	965.970	521.582
1903	MBN-6	Surabaya	Kumai	544.796	294.166
	MBN-7	Kumai	Semarang	508.769	274.713
	MBN-8	Semarang	Surabaya	352.769	190.480

Voyage Number	Trip Number	Route		Distance Sailed	
		Origin	Destination	km	nm
1904	MBN-9	Surabaya	Sampit	532.765	287.670
	MBN-10	Sampit	Surabaya	529.806	286.072
1905	MBN-11	Surabaya	Semarang	354.899	191.630
	MBN-12	Semarang	Kumai	512.559	276.760
	MBN-13	Kumai	Surabaya	542.409	292.877
1906	MBN-14	Surabaya	Kumai	541.504	292.389
	MBN-15	Kumai	Surabaya	539.432	291.270
1907	MBN-16	Surabaya	Kumai	540.671	291.939
	MBN-17	Kumai	Surabaya	539.839	291.490
1908	MBN-18	Surabaya	Kumai	542.040	292.678
	MBN-19	Kumai	Semarang	508.337	274.480
	MBN-20	Semarang	Surabaya	356.252	192.360
1909	MBN-21	Surabaya	Kumai	540.993	292.113
	MBN-22	Kumai	Semarang	506.528	273.504
	MBN-23	Semarang	Surabaya	358.647	193.654
1910	MBN-24	Surabaya	Kumai	542.810	293.094
	MBN-25	Kumai	Semarang	506.595	273.540
	MBN-26	Semarang	Surabaya	358.384	193.512

Table 4. 10 Distance Sailed by MV Meratus Bontang
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Distance Sailed	
		Origin	Destination	km	nm
1901	MBT-1	Semarang	Pontianak	868.918	469.178
	MBT-2	Pontianak	Semarang	847.419	457.570
1902	MBT-3	Semarang	Pontianak	846.604	457.130
	MBT-4	Pontianak	Semarang	840.450	453.807
1903	MBT-5	Semarang	Pontianak	856.527	462.488
	MBT-6	Pontianak	Surabaya	1043.220	563.294
1904	MBT-7	Surabaya	Sampit	550.419	297.203
	MBT-8	Sampit	Surabaya	520.477	281.035

Voyage Number	Trip Number	Route		Distance Sailed	
		Origin	Destination	km	nm
1905	MBT-9	Surabaya	Kumai	585.189	315.977
	MBT-10	Kumai	Semarang	507.679	274.125
	MBT-11	Semarang	Surabaya	357.198	192.872
1906	MBT-12	Surabaya	Sampit	511.828	276.365
	MBT-13	Sampit	Surabaya	511.975	276.444
1907	MBT-14	Surabaya	Sampit	516.230	278.742
	MBT-15	Sampit	Surabaya	530.130	286.247
1908	MBT-16	Surabaya	Kumai	541.681	292.484
	MBT-17	Kumai	Surabaya	544.300	293.899
1909	MBT-18	Surabaya	Semarang	347.470	187.619
	MBT-19	Semarang	Kumai	503.150	271.679
	MBT-20	Kumai	Surabaya	546.419	295.043
1910	MBT-21	Surabaya	Semarang	352.542	190.358
	MBT-22	Semarang	Kumai	503.762	272.010
	MBT-23	Kumai	Surabaya	536.488	289.680

4.1.6. Weather Condition

During the sea voyage, the sea condition or sea state is noted inside the noon report. The sea state is expressed in a scale of Beaufort.

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Table 4. 11 Average Sea State during Voyage
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Average Sea State
		Origin	Destination	Beaufort
1901	MBN-1	Surabaya	Kumai	1
	MBN-2	Kumai	Semarang	3
	MBN-3	Semarang	Surabaya	2
1902	MBN-4	Surabaya	Samarinda	2
	MBN-5	Samarinda	Surabaya	4
1903	MBN-6	Surabaya	Kumai	4

Voyage Number	Trip Number	Route		Average Sea State
		Origin	Destination	Beaufort
1903	MBN-7	Kumai	Semarang	2
	MBN-8	Semarang	Surabaya	1
1904	MBN-9	Surabaya	Sampit	2
	MBN-10	Sampit	Surabaya	2
1905	MBN-11	Surabaya	Semarang	1
	MBN-12	Semarang	Kumai	3
	MBN-13	Kumai	Surabaya	3
1906	MBN-14	Surabaya	Kumai	3
	MBN-15	Kumai	Surabaya	1
1907	MBN-16	Surabaya	Kumai	(Unnoted)
	MBN-17	Kumai	Surabaya	3
1908	MBN-18	Surabaya	Kumai	1
	MBN-19	Kumai	Semarang	4
	MBN-20	Semarang	Surabaya	(Unnoted)
1909	MBN-21	Surabaya	Kumai	1
	MBN-22	Kumai	Semarang	3
	MBN-23	Semarang	Surabaya	(Unnoted)
1910	MBN-24	Surabaya	Kumai	(Unnoted)
	MBN-25	Kumai	Semarang	1
	MBN-26	Semarang	Surabaya	1

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Table 4. 12 Average Sea State during Voyage
Source: PT Meratus Line Shipping Company

Voyage Number	Trip Number	Route		Average Sea State
		Origin	Destination	Beaufort
1901	MBT-1	Semarang	Pontianak	3
	MBT-2	Pontianak	Semarang	4
1902	MBT-3	Semarang	Pontianak	3
	MBT-4	Pontianak	Semarang	3
1903	MBT-5	Semarang	Pontianak	5
	MBT-6	Pontianak	Surabaya	3
1904	MBT-7	Surabaya	Sampit	(Unnoted)

Voyage Number	Trip Number	Route		Average Sea State
		Origin	Destination	Beaufort
1904	MBT-8	Sampit	Surabaya	(Unnoted)
1905	MBT-9	Surabaya	Kumai	3
	MBT-10	Kumai	Semarang	3
	MBT-11	Semarang	Surabaya	3
1906	MBT-12	Surabaya	Sampit	3
	MBT-13	Sampit	Surabaya	3
1907	MBT-14	Surabaya	Sampit	2
	MBT-15	Sampit	Surabaya	3
1908	MBT-16	Surabaya	Kumai	3
	MBT-17	Kumai	Surabaya	(Unnoted)
1909	MBT-18	Surabaya	Semarang	3
	MBT-19	Semarang	Kumai	3
	MBT-20	Kumai	Surabaya	3
1910	MBT-21	Surabaya	Semarang	3
	MBT-22	Semarang	Kumai	(Unnoted)
	MBT-23	Kumai	Surabaya	3

4.2. Fuel Oil Consumption Estimation

Estimation of fuel oil consumption is specifically for the main engine fuel oil consumption during the ship's cruising mode. Therefore, these methods only estimate the consumption of MFO for MV Meratus Benoa and MV Meratus Bontang.

4.2.1. Bialystocki and Konovessis' Method

Bialystocki and Konovessis utilize statistical data compiled from noon reports. This research makes use of noon reports over the time of 10 voyages, voyage 1901 – 1910. From the noon report, daily fuel consumption could be obtained.

In the preliminary stage, the fuel oil consumption recorded in the noon report will be corrected with the steaming time as in Formula (1), and the actual displacement of the voyage as in Formula (2).

The corrections are plotted to form a preliminary curve:

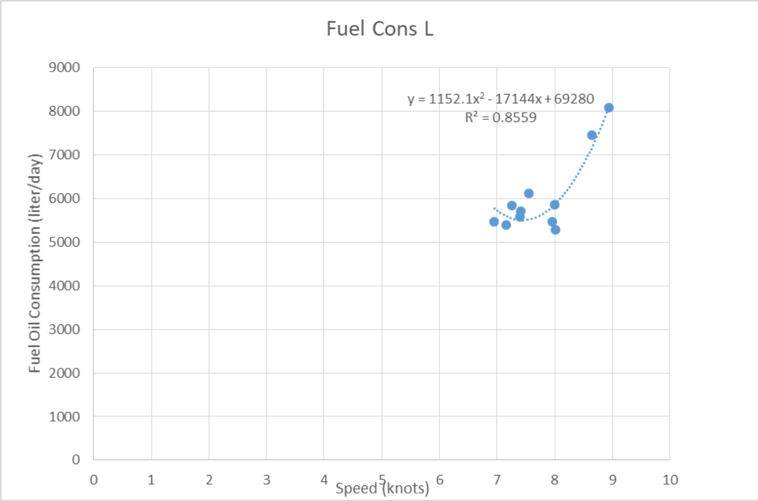

Figure 4. 1 Preliminary Curve of Fuel Oil Consumption

Based on the result of **Figure 4.1**, the starting R-square value is 0.8559 with a rather wide scatter. This means further corrections are needed before any conclusion could be taken.

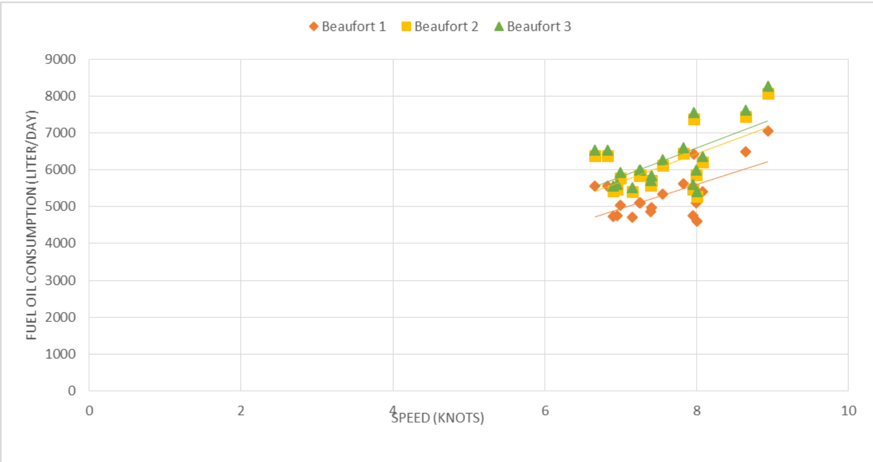

Figure 4. 2 Fuel Consumption per Beaufort Scale

Figure 4.2 shows that fuel oil consumption increases as the weather goes worse. This average lines of fuel consumption in specific weather condition then used for the correction as in Formula (3).

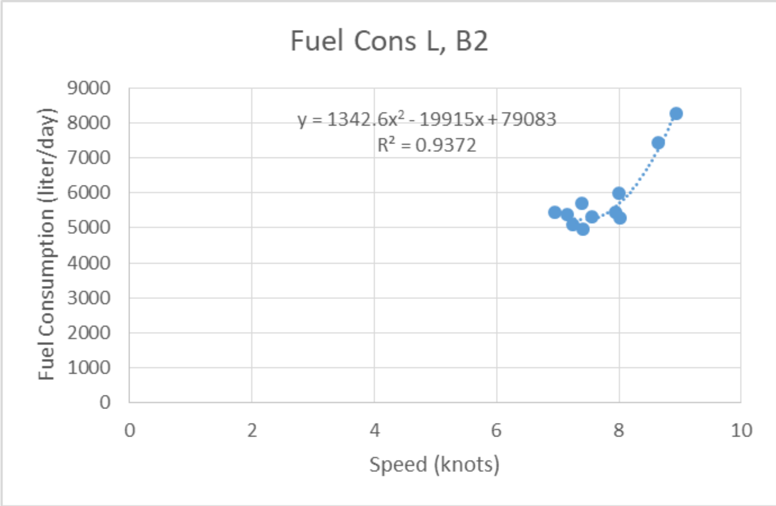

Figure 4. 3 First Weather Correction of Fuel Consumption

Figure 4.3 shows an increased result of R-square compared to the preliminary fuel oil consumption graph. R-square value risen from **0.8859** to **0.9372**. Increased R-square indicates that correction of weather condition made the data is less scattered compared to the preliminary stage, hence could suggest that the first weather correction resulted in increased accuracy towards the fuel oil consumption estimation.

The second weather correction is to correct the ship's fuel oil consumption towards the weather direction, following Formula (4).

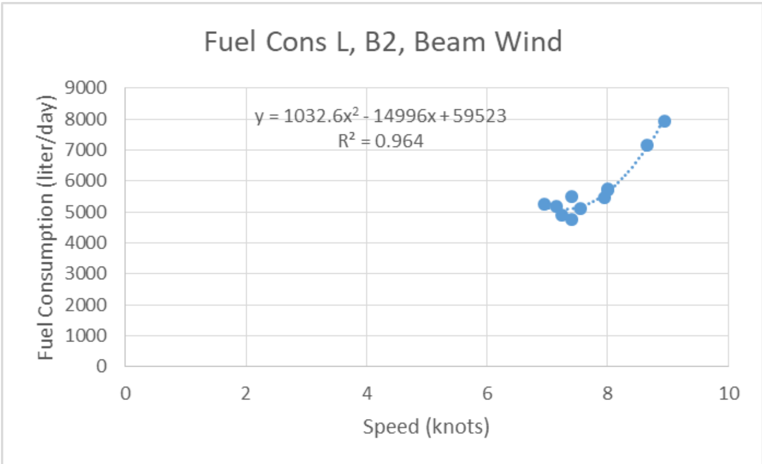

Figure 4. 4 Second Weather Correction of Fuel Consumption

Figure 4.4 shows the trend line with an increase of R-square value compared to the first weather correction, with higher R-square value of **0.964**. The graph indicates a better accuracy than the first weather correction.

Estimation of fuel oil consumption could be made from **Figure 4.4** with formula as follow

$$y = 1032.6x^2 - 14996x + 59523 \quad (25)$$

Where:

y: Daily fuel oil consumption (liter/day)

x: Speed (knots)

The result of fuel oil consumption estimation using Bialystocki and Konovessis' method

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Table 4. 13 MV Meratus Benoa Bialystocki and Konovessis' Estimation Result

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Avg. Vs (Knot)	Estimation FOC	
		Origin	Destination	Hours	Day		Daily (Liter/Day)	Total (Liter)
1901	MBN-1	Surabaya	Kumai	33.400	1.392	9.106	8,591.83	11,956.96
	MBN-2	Kumai	Semarang	32.000	1.333	7.532	5,153.58	6,871.44
	MBN-3	Semarang	Surabaya	17.500	0.729	9.194	8,935.08	6,515.16
1902	MBN-4	Surabaya	Samarinda	63.500	2.646	8.086	5,780.24	15,293.55
	MBN-5	Samarinda	Surabaya	65.000	2.708	7.018	5,139.02	13,918.18
1903	MBN-6	Surabaya	Kumai	45.700	1.904	7.627	5,216.02	9,932.16
	MBN-7	Kumai	Semarang	34.400	1.433	7.087	5,109.27	7,323.29
	MBN-8	Semarang	Surabaya	21.200	0.883	8.321	6,237.52	5,509.81
1904	MBN-9	Surabaya	Sampit	28.800	1.200	7.375	5,091.26	6,109.51
	MBN-10	Sampit	Surabaya	29.300	1.221	7.610	5,203.47	6,352.58
1905	MBN-11	Surabaya	Semarang	22.600	0.942	8.567	6,838.38	6,439.48
	MBN-12	Semarang	Kumai	28.800	1.200	8.240	6,067.02	7,280.43
	MBN-13	Kumai	Surabaya	30.200	1.258	7.873	5,464.30	6,875.92
1906	MBN-14	Surabaya	Kumai	37.700	1.571	6.642	5,473.92	8,598.61
	MBN-15	Kumai	Surabaya	30.900	1.288	8.148	5,889.81	7,583.13
1907	MBN-16	Surabaya	Kumai	35.500	1.479	7.081	5,111.47	7,560.71
	MBN-17	Kumai	Surabaya	31.200	1.300	7.790	5,366.56	6,976.53
1908	MBN-18	Surabaya	Kumai	31.400	1.308	8.323	6,241.90	8,166.48
	MBN-19	Kumai	Semarang	31.500	1.313	7.703	5,279.38	6,929.19

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Avg. Vs (Knot)	Estimation FOC	
		Origin	Destination	Hours	Day		Daily (Liter/Day)	Total (Liter)
1908	MBN-20	Semarang	Surabaya	20.200	0.842	7.683	5,261.55	4,428.47
1909	MBN-21	Surabaya	Kumai	26.800	1.117	8.663	7,106.77	7,935.90
	MBN-22	Kumai	Semarang	29.700	1.238	7.867	5,456.76	6,752.74
	MBN-23	Semarang	Surabaya	20.000	0.833	7.935	5,546.60	4,622.17
1910	MBN-24	Surabaya	Kumai	35.200	1.467	6.810	5,288.20	7,756.03
	MBN-25	Kumai	Semarang	35.200	1.467	6.726	5,373.77	7,881.54
	MBN-26	Semarang	Surabaya	19.200	0.800	8.229	6,044.91	4,835.93

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Table 4. 14 MV Meratus Bontang Bialystocki and Konovessis' Estimation Result

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Avg. Vs (Knot)	Estimation	
		Origin	Destination	Hours	Day		Daily (Liter/Day)	Total (Liter)
1901	MBT-1	Semarang	Pontianak	54.40	3.400	7.570	5,176.32	17,599.49
	MBT-2	Pontianak	Semarang	47.30	1.971	8.508	6,682.88	13,170.85
1902	MBT-3	Semarang	Pontianak	56.20	2.342	7.263	5,077.91	11,890.77
	MBT-4	Pontianak	Semarang	45.00	1.875	9.053	8,392.81	15,736.52
1903	MBT-5	Semarang	Pontianak	49.90	2.079	8.036	5,697.66	11,846.38
	MBT-6	Pontianak	Surabaya	53.20	2.217	8.506	6,677.74	14,802.32
1904	MBT-7	Surabaya	Sampit	28.00	1.167	7.743	5,317.52	6,203.78
	MBT-8	Sampit	Surabaya	24.50	1.021	8.193	5,974.30	6,098.77
1905	MBT-9	Surabaya	Kumai	30.20	1.258	8.363	6,331.26	7,966.83
	MBT-10	Kumai	Semarang	29.60	1.233	7.480	5,127.30	6,323.67
	MBT-11	Semarang	Surabaya	15.50	0.646	8.048	5,717.01	3,692.23
1906	MBT-12	Surabaya	Sampit	27.00	1.125	7.089	5,108.55	5,747.12
	MBT-13	Sampit	Surabaya	23.40	0.975	8.057	5,731.71	5,588.42
1907	MBT-14	Surabaya	Sampit	19.30	0.804	8.248	6,083.26	4,891.95
	MBT-15	Sampit	Surabaya	24.00	1.000	9.403	9,814.40	9,814.40
1908	MBT-16	Surabaya	Kumai	31.00	1.292	7.304	5,079.79	6,561.40
	MBT-17	Kumai	Surabaya	24.50	1.021	8.806	7,541.85	7,698.97

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Avg. Vs (Knot)	Estimation	
		Origin	Destination	Hours	Day		Daily (Liter/Day)	Total (Liter)
1909	MBT-18	Surabaya	Semarang	20.10	0.838	7.038	5,129.39	4,295.86
	MBT-19	Semarang	Kumai	24.40	1.017	8.117	5,834.03	5,931.26
	MBT-20	Kumai	Surabaya	23.00	0.958	8.768	7,422.11	7,112.86
1910	MBT-21	Surabaya	Semarang	12.00	0.500	9.587	10,663.20	5,331.60
	MBT-22	Semarang	Kumai	27.30	1.138	7.883	5,477.04	6,230.13
	MBT-23	Kumai	Surabaya	27.40	1.142	8.361	6,326.71	7,223.00

4.2.2. Moreno-Gutiérrez, et al.'s Method

This method needs some assumptions for the ship's technical calculation, particularly for determining the ship's propulsive efficiency that needs to be modified according to the method.

For coefficient block from formula (11), resulted

$$\boldsymbol{C_b = 0.801}$$

Calculation of wetted surface area, formula (12) resulted

$$\boldsymbol{S = 2964.583\ m^2}$$

Formula (7) resulted frictional resistance coefficient (C_F), formula (8) resulted incremental resistance coefficient (C_A)

$$\boldsymbol{C_F = 0.0016}$$

$$\boldsymbol{C_A = 0.000435}$$

Then formula (9) and (10) resulted in air resistance coefficient and residual resistance coefficient

$$\boldsymbol{C_{AA} = 0.0000133}$$

$$\boldsymbol{C_R = 0.63462}$$

Total resistance coefficient than could be summed with the formula (6)

$$\boldsymbol{C_T = 0.6366}$$

And total resistance of the ship could be calculated with the formula (5)

$$\boldsymbol{R_T = 33,852.956\ kN}$$

Effective towing power is calculated using formula (14) which resulted

$$\boldsymbol{P_E = 200,277.47\ kW}$$

Thrust power then determined using formula (15) that resulted

$$P_T = 196,350.46\ kW$$

Power delivered to the propeller is calculated with the formula (16)

$$P_D = 333,929.36\ kW$$

Propulsive efficiency then could be determined with the formula (13) that resulted

$$\eta_D = 0.698$$

Modification of propulsive efficiency then calculated with the formula (17) and (18)

$$\eta_f = 0.608$$

$$\eta_w = 0.598$$

Power transient then calculated with the formula (20) for determining the load factor of the main engine with the formula (19). $SFOC_{relative}$ then could be identified with load factor using formula (20). $SFOC$ of the main engine then could be calculated for day-to-day time range based on the ship operational condition taken from the noon reports. The calculation of $SFOC$ using formula (21) resulted

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Table 4. 15 Calculation Results of Formula (19), (20), and (21)

Voyage Number	Trip Number	Route		$P_{transient}$	Load Factor	SFOC Relative	SFOC (g/kWh)
		Origin	Destination				
1901	MBN-1	Surabaya	Kumai	1620.94	0.844	1.005	200.977
	MBN-2	Kumai	Semarang	1669.26	0.869	1.007	201.328
	MBN-3	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1902	MBN-4	Surabaya	Samarinda	1463.65	0.762	1.003	200.634
	MBN-5	Samarinda	Surabaya	1734.90	0.904	1.010	201.989
1903	MBN-6	Surabaya	Kumai	501.36	0.261	1.126	225.125
	MBN-7	Kumai	Semarang	1655.64	0.862	1.006	201.218
	MBN-8	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1904	MBN-9	Surabaya	Sampit	2417.32	1.259	1.107	221.466
	MBN-10	Sampit	Surabaya	1737.05	0.905	1.010	202.015
1905	MBN-11	Surabaya	Semarang	2353.36	1.226	1.093	218.664
	MBN-12	Semarang	Kumai	2579.69	1.344	1.147	229.486
	MBN-13	Kumai	Surabaya	1826.35	0.951	1.016	203.265

Voyage Number	Trip Number	Route		$P_{transient}$	Load Factor	SFOC Relative	SFOC (g/kWh)
		Origin	Destination				
1906	MBN-14	Surabaya	Kumai	964.45	0.502	1.038	207.632
	MBN-15	Kumai	Surabaya	1883.22	0.981	1.021	204.267
1907	MBN-16	Surabaya	Kumai	1275.53	0.664	1.009	201.826
	MBN-17	Kumai	Surabaya	1801.79	0.938	1.014	202.882
1908	MBN-18	Surabaya	Kumai	1275.53	0.664	1.009	201.826
	MBN-19	Kumai	Semarang	1444.48	0.752	1.003	200.675
	MBN-20	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1909	MBN-21	Surabaya	Kumai	3785.15	1.971	1.649	329.732
	MBN-22	Kumai	Semarang	2019.35	1.052	1.037	207.313
	MBN-23	Semarang	Surabaya	2674.39	1.393	1.174	234.765
1910	MBN-24	Surabaya	Kumai	3785.15	1.971	1.649	329.732
	MBN-25	Kumai	Semarang	1262.72	0.658	1.010	201.971
	MBN-26	Semarang	Surabaya	2674.39	1.393	1.174	234.765

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Table 4. 16 Calculation Results of Formula (19), (20), and (21)

Voyage Number	Trip Number	Route		$P_{transient}$	Load Factor	SFOC Relative	SFOC (g/kWh)
		Origin	Destination				
1901	MBT-1	Semarang	Pontianak	1155.71	0.602	1.017	203.497
	MBT-2	Pontianak	Semarang	1788.60	0.932	1.013	202.689
1902	MBT-3	Semarang	Pontianak	1534.91	0.799	1.003	200.638
	MBT-4	Pontianak	Semarang	2562.49	1.335	1.143	228.575
1903	MBT-5	Semarang	Pontianak	1840.86	0.959	1.018	203.506
	MBT-6	Pontianak	Surabaya	2766.37	1.441	1.202	240.316
1904	MBT-7	Surabaya	Sampit	1806.68	0.941	1.015	202.956
	MBT-8	Sampit	Surabaya	1911.75	0.996	1.024	204.830
1905	MBT-9	Surabaya	Kumai	1502.57	0.783	1.003	200.605
	MBT-10	Kumai	Semarang	1588.32	0.827	1.004	200.806
	MBT-11	Semarang	Surabaya	1435.22	0.748	1.004	200.702
1906	MBT-12	Surabaya	Sampit	1806.68	0.941	1.015	202.956
	MBT-13	Sampit	Surabaya	1911.75	0.996	1.024	204.830
1907	MBT-14	Surabaya	Sampit	2309.49	1.203	1.084	216.859
	MBT-15	Sampit	Surabaya	1832.23	0.954	1.017	203.362
1908	MBT-16	Surabaya	Kumai	588.57	0.307	1.105	221.022

Voyage Number	Trip Number	Route		$P_{transient}$	Load Factor	SFOC Relative	SFOC (g/kWh)
		Origin	Destination				
1908	MBT-17	Kumai	Surabaya	2220.67	1.157	1.067	213.495
1909	MBT-18	Surabaya	Semarang	1111.38	0.579	1.021	204.295
1909	MBT-19	Semarang	Kumai	2280.12	1.188	1.079	215.704
	MBT-20	Kumai	Surabaya	2830.74	1.474	1.222	244.449
1910	MBT-21	Surabaya	Semarang	1111.38	0.579	1.021	204.295
	MBT-22	Semarang	Kumai	2280.12	1.188	1.079	215.704
	MBT-23	Kumai	Surabaya	2220.67	1.157	1.067	213.495

During their operational time, MV Meratus Benoa and Meratus Bontang operated with various main engine power. The fuel oil consumption estimation using Moreno-Gutiérrez, et al.'s method as follows

MV Meratus Benoa

Table 4. 17 MV Meratus Benoa Moreno-Gutiérrez, et al.'s Estimation Result

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea Voyage (Hour)	M/E FOC (Ton)
		Origin	Destination				
1901	MBN-1	Surabaya	Kumai	993.14	0.1996	33.4	6.667
	MBN-2	Kumai	Semarang	1143.07	0.2301	32.0	7.364
	MBN-3	Semarang	Surabaya	1143.07	0.2499	17.5	4.374
1902	MBN-4	Surabaya	Samarinda	1143.07	0.2293	63.5	14.563
	MBN-5	Samarinda	Surabaya	1143.07	0.2309	65.0	15.008
1903	MBN-6	Surabaya	Kumai	897.32	0.2020	45.7	9.232
	MBN-7	Kumai	Semarang	1143.07	0.2300	34.4	7.912
	MBN-8	Semarang	Surabaya	1143.07	0.2499	21.2	5.299
1904	MBN-9	Surabaya	Sampit	1143.07	0.2532	28.8	7.291
	MBN-10	Sampit	Surabaya	993.14	0.2006	29.3	5.878
1905	MBN-11	Surabaya	Semarang	1143.07	0.2499	22.6	5.649
	MBN-12	Semarang	Kumai	1143.07	0.2623	28.8	7.555
	MBN-13	Kumai	Surabaya	897.32	0.1824	30.2	5.508
1906	MBN-14	Surabaya	Kumai	897.32	0.1863	37.7	7.024
	MBN-15	Kumai	Surabaya	897.32	0.1833	30.9	5.664
1907	MBN-16	Surabaya	Kumai	993.14	0.2004	35.5	7.116
	MBN-17	Kumai	Surabaya	993.14	0.2015	31.2	6.286
1908	MBN-18	Surabaya	Kumai	993.14	0.2004	31.4	6.294

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea Voyage (Hour)	M/E FOC (Ton)
		Origin	Destination				
1908	MBN-19	Kumai	Semarang	897.32	0.1801	31.5	5.672
	MBN-20	Semarang	Surabaya	1143.07	0.2499	20.2	5.049
1909	MBN-21	Surabaya	Kumai	993.14	0.3275	26.8	8.776
	MBN-22	Kumai	Semarang	993.14	0.2059	29.7	6.115
	MBN-23	Semarang	Surabaya	1086.29	0.2550	20.0	5.100
1910	MBN-24	Surabaya	Kumai	993.14	0.3275	35.2	11.527
	MBN-25	Kumai	Semarang	897.32	0.1812	35.2	6.379
	MBN-26	Semarang	Surabaya	1086.29	0.2550	19.2	4.896

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Table 4. 18 MV Meratus Bontang Moreno-Gutiérrez, et al.'s Estimation Result

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea Voyage (Hour)	M/E FOC (Ton)
		Origin	Destination				
1901	MBT-1	Semarang	Pontianak	1143.065	0.2326	54.4	12.654
	MBT-2	Pontianak	Semarang	1143.065	0.2317	47.3	10.959
1902	MBT-3	Semarang	Pontianak	1143.065	0.2293	56.2	12.889
	MBT-4	Pontianak	Semarang	1143.065	0.2613	45.0	11.757
1903	MBT-5	Semarang	Pontianak	1143.065	0.2326	49.9	11.608
	MBT-6	Pontianak	Surabaya	1143.065	0.2747	53.2	14.614
1904	MBT-7	Surabaya	Sampit	1143.065	0.2320	28.0	6.496
	MBT-8	Sampit	Surabaya	1143.065	0.2341	24.5	5.736
1905	MBT-9	Surabaya	Kumai	1143.065	0.2293	30.2	6.925
	MBT-10	Kumai	Semarang	1143.065	0.2295	29.6	6.794
	MBT-11	Semarang	Surabaya	1143.065	0.2294	15.5	3.556
1906	MBT-12	Surabaya	Sampit	1143.065	0.2320	27.0	6.264
	MBT-13	Sampit	Surabaya	1143.065	0.2341	23.4	5.479
1907	MBT-14	Surabaya	Sampit	1143.065	0.2479	19.3	4.784
	MBT-15	Sampit	Surabaya	1143.065	0.2325	24.0	5.579
1908	MBT-16	Surabaya	Kumai	1143.065	0.2526	31.0	7.832
	MBT-17	Kumai	Surabaya	1143.065	0.2440	24.5	5.979
1909	MBT-18	Surabaya	Semarang	1143.065	0.2335	20.1	4.694
	MBT-19	Semarang	Kumai	1143.065	0.2466	24.4	6.016

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea Voyage (Hour)	M/E FOC (Ton)
		Origin	Destination				
1909	MBT-20	Kumai	Surabaya	1143.065	0.2794	23.0	6.427
1910	MBT-21	Surabaya	Semarang	1143.065	0.2335	12.0	2.802
	MBT-22	Semarang	Kumai	1143.065	0.2466	27.3	6.731
	MBT-23	Kumai	Surabaya	1143.065	0.2440	27.4	6.687

4.3. Analysis of Calculation Error

4.3.1. Analysis of Fuel Oil Consumption Estimation Error

The error of fuel oil consumption estimation could be calculated with absolute percentage error, with formulas as follows:

$$\textit{Absolute Percentage Error} = \left(\frac{|A_t - F_t|}{A_t}\right) \times 100\% \quad (25)$$

$$\textit{Mean APE} = \sum_{t=1}^{n} \left(\frac{|A_t - F_t|}{A_t}\right) \times \frac{100\%}{n} \quad (26)$$

Where:
A_t : Actual value
F_t : Forecast value
n : Number of calculated values

1. Bialystocki and Konovessis' Method

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Table 4. 19 MV Meratus Benoa Calculation Error of Bialystocki and Konovessi's Method

Voyage Number	Trip Number	Route		Estimation FOC (Liter)	Actual FOC (Liter)	Error
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	6,915	11,956.96	72.91%
	MBN-2	Kumai	Semarang	7,300	6,871.44	5.87%
	MBN-3	Semarang	Surabaya	5,134	6,515.16	26.90%
1902	MBN-4	Surabaya	Samarinda	13,795	15,293.55	10.86%
	MBN-5	Samarinda	Surabaya	23,028	13,918.18	39.56%
1903	MBN-6	Surabaya	Kumai	13,041	9,932.16	23.84%
	MBN-7	Kumai	Semarang	7,988	7,323.29	8.32%
	MBN-8	Semarang	Surabaya	4,240	5,509.81	29.95%
1904	MBN-9	Surabaya	Sampit	11,047	6,109.51	44.70%

Voyage Number	Trip Number	Route		Estimation FOC (Liter)	Actual FOC (Liter)	Error
		Origin	Destination			
1904	MBN-10	Sampit	Surabaya	6,944	6,352.58	8.52%
1905	MBN-11	Surabaya	Semarang	5,150	6,439.48	25.04%
	MBN-12	Semarang	Kumai	7,797	7,280.43	6.63%
	MBN-13	Kumai	Surabaya	6,553	6,875.92	4.93%
1906	MBN-14	Surabaya	Kumai	7,540	8,598.61	14.04%
	MBN-15	Kumai	Surabaya	6,694	7,583.13	13.28%
1907	MBN-16	Surabaya	Kumai	8,206	7,560.71	7.86%
	MBN-17	Kumai	Surabaya	6,864	6,976.53	1.64%
1908	MBN-18	Surabaya	Kumai	9,261	8,166.48	11.82%
	MBN-19	Kumai	Semarang	11,894	6,929.19	41.74%
	MBN-20	Semarang	Surabaya	4,554	4,428.47	2.76%
1909	MBN-22	Kumai	Semarang	11,561	6,752.74	41.59%
	MBN-23	Semarang	Surabaya	4,534	4,622.17	1.94%
1910	MBN-24	Surabaya	Kumai	10,571	7,756.03	26.63%
	MBN-25	Kumai	Semarang	8,139	7,881.54	3.16%
	MBN-26	Semarang	Surabaya	4,416	4,835.93	9.51%

Mean absolute percentage error of MV Meratus Benoa using Bialystocki and Konovessis's method is **19.958%**.

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Table 4. 20 MV Meratus Bontang Calculation Error of Bialystocki and Konovessis' Method

Voyage Number	Trip Number	Route		Estimation FOC (Liter)	Actual FOC (Liter)	Error
		Origin	Destination			
1901	MBT-1	Semarang	Pontianak	11,968	17,599.49	47.05%
	MBT-2	Pontianak	Semarang	10,406	13,170.85	26.57%
1902	MBT-3	Semarang	Pontianak	12,688	11,890.77	6.28%
	MBT-4	Pontianak	Semarang	9,900	15,736.52	58.95%
1903	MBT-5	Semarang	Pontianak	17,694	11,846.38	33.05%
	MBT-6	Pontianak	Surabaya	11,704	14,802.32	26.47%
1904	MBT-7	Surabaya	Sampit	6,160	6,203.78	0.71%
	MBT-8	Sampit	Surabaya	5,390	6,098.77	13.15%
1905	MBT-9	Surabaya	Kumai	6,644	7,966.83	19.91%

Voyage Number	Trip Number	Route		Estimation FOC (Liter)	Actual FOC (Liter)	Error
		Origin	Destination			
1905	MBT-10	Kumai	Semarang	6,512	6,323.67	2.89%
	MBT-11	Semarang	Surabaya	3,410	3,692.23	8.28%
1906	MBT-12	Surabaya	Sampit	5,940	5,747.12	3.25%
	MBT-13	Sampit	Surabaya	5,148	5,588.42	8.56%
1907	MBT-14	Surabaya	Sampit	4,246	4,891.95	15.21%
	MBT-15	Sampit	Surabaya	5,280	9,814.40	85.88%
1908	MBT-16	Surabaya	Kumai	6,820	6,561.40	3.79%
	MBT-17	Kumai	Surabaya	5,390	7,698.97	42.84%
1909	MBT-18	Surabaya	Semarang	4,422	4,295.86	2.85%
	MBT-19	Semarang	Kumai	5,368	5,931.26	10.49%
	MBT-20	Kumai	Surabaya	5,060	7,112.86	40.57%
1910	MBT-21	Surabaya	Semarang	5,280	5,331.60	0.98%
	MBT-22	Semarang	Kumai	6,006	6,230.13	3.73%
	MBT-23	Kumai	Surabaya	6,028	7,223.00	19.82%

Mean absolute percentage error of MV Meratus Bontang using Bialystocki and Konovessis' method is **20.926%**.

2. **Moreno-Gutiérrez, et al.'s**
   MV Meratus Benoa

Table 4. 21 MV Meratus Benoa Calculation Error of Moreno-Gutiérrez, et al.'s Method

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	6.667	6.853	2.72%
	MBN-2	Kumai	Semarang	7.364	7.234	1.80%
	MBN-3	Semarang	Surabaya	4.374	5.088	14.03%
1902	MBN-4	Surabaya	Samarinda	14.563	13.671	6.53%
	MBN-5	Samarinda	Surabaya	15.008	22.821	34.24%
1903	MBN-6	Surabaya	Kumai	9.232	12.924	28.57%
	MBN-7	Kumai	Semarang	7.912	7.916	0.05%
	MBN-8	Semarang	Surabaya	5.299	4.202	26.11%
1904	MBN-9	Surabaya	Sampit	7.291	10.948	33.40%
	MBN-10	Sampit	Surabaya	5.878	6.882	14.58%
1905	MBN-11	Surabaya	Semarang	5.649	5.104	10.68%

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destination			
1905	MBN-12	Semarang	Kumai	7.555	7.727	2.23%
	MBN-13	Kumai	Surabaya	5.508	6.494	15.18%
1906	MBN-14	Surabaya	Kumai	7.024	7.472	6.00%
	MBN-15	Kumai	Surabaya	5.664	6.634	14.62%
1907	MBN-16	Surabaya	Kumai	7.116	8.132	12.50%
	MBN-17	Kumai	Surabaya	6.286	6.802	7.58%
1908	MBN-18	Surabaya	Kumai	6.294	9.178	31.42%
	MBN-19	Kumai	Semarang	5.672	11.787	51.88%
	MBN-20	Semarang	Surabaya	5.049	4.513	11.88%
1909	MBN-21	Surabaya	Kumai	8.776	12.084	27.38%
	MBN-22	Kumai	Semarang	6.115	11.457	46.63%
	MBN-23	Semarang	Surabaya	5.100	4.493	13.52%
1910	MBN-24	Surabaya	Kumai	11.527	10.476	10.03%
	MBN-25	Kumai	Semarang	6.379	8.066	20.91%
	MBN-26	Semarang	Surabaya	4.896	4.376	11.89%

Mean absolute percentage error of MV Meratus Benoa using Moreno-Gutiérrez, et al.'s method is **17.550%**.

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Table 4. 22 MV Meratus Bontang Calculation Error of Moreno-Gutiérrez, et al.'s Method

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destination			
1901	MBT-1	Semarang	Pontianak	12.654	11.860	6.69%
	MBT-2	Pontianak	Semarang	10.959	10.312	6.27%
1902	MBT-3	Semarang	Pontianak	12.889	12.574	2.51%
	MBT-4	Pontianak	Semarang	11.757	9.811	19.84%
1903	MBT-5	Semarang	Pontianak	11.608	17.535	33.80%
	MBT-6	Pontianak	Surabaya	14.614	11.599	26.00%
1904	MBT-7	Surabaya	Sampit	6.496	6.105	6.41%
	MBT-8	Sampit	Surabaya	5.736	5.341	7.39%
1905	MBT-9	Surabaya	Kumai	6.925	6.584	5.18%
	MBT-10	Kumai	Semarang	6.794	6.453	5.28%
	MBT-11	Semarang	Surabaya	3.556	3.379	5.23%

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destination			
1906	MBT-12	Surabaya	Sampit	6.264	5.887	6.41%
	MBT-13	Sampit	Surabaya	5.479	5.102	7.39%
1907	MBT-14	Surabaya	Sampit	4.784	4.208	13.70%
	MBT-15	Sampit	Surabaya	5.579	5.232	6.62%
1908	MBT-16	Surabaya	Kumai	7.832	6.759	15.88%
	MBT-17	Kumai	Surabaya	5.979	5.341	11.93%
1909	MBT-18	Surabaya	Semarang	4.694	4.382	7.11%
	MBT-19	Semarang	Kumai	6.016	5.320	13.09%
	MBT-20	Kumai	Surabaya	6.427	5.014	28.16%
1910	MBT-21	Surabaya	Semarang	2.802	5.232	46.44%
	MBT-22	Semarang	Kumai	6.731	5.952	13.09%
	MBT-23	Kumai	Surabaya	6.687	5.974	11.93%

Mean absolute percentage error of MV Meratus Benoa using Moreno-Gutiérrez, et al.'s method is **13.320%**.

4.4. EEOI Calculation Results

4.4.1. EEOI Calculation with Actual Fuel Oil Consumption

According to the guidelines of EEOI, data of fuel oil consumption, cargo carried, and distance sailed is calculated with the formula (23) and resulted as follow

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Table 4. 23 MV Meratus Benoa EEOI Calculation Results

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)		Cargo Carried	Distance Sailed	EEOI (Ton CO2/TEU-nm)
		Origin	Destination	MFO	HSD	TEUs	nm	
1901	MBN-1	Surabaya	Kumai	6.853	8.386	162	295.482	0.000836
	MBN-2	Kumai	Semarang	7.234	9.139	198	271.932	0.000797
	MBN-3	Semarang	Surabaya	5.088	3.344	147	193.150	0.000821
1902	MBN-4	Surabaya	Samarinda	13.671	10.351	187	522.215	0.000672
	MBN-5	Samarinda	Surabaya	22.821	12.372	182	521.582	0.001039
1903	MBN-6	Surabaya	Kumai	12.924	11.168	221	294.166	0.001002
	MBN-7	Kumai	Semarang	7.916	8.432	268	274.713	0.000590
	MBN-8	Semarang	Surabaya	4.202	2.744	163	190.480	0.000618

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)		Cargo Carried	Distance Sailed	EEOI (Ton CO2/TEU-nm)
		Origin	Destination	MFO	HSD	TEUs	nm	
1904	MBN-9	Surabaya	Sampit	10.948	8.195	215	287.670	0.000847
	MBN-10	Sampit	Surabaya	6.882	8.134	112	286.072	0.001235
1905	MBN-11	Surabaya	Semarang	5.104	9.693	178	191.630	0.001099
	MBN-12	Semarang	Kumai	7.727	2.822	221	276.760	0.000496
	MBN-13	Kumai	Surabaya	6.494	7.679	174	292.877	0.000733
1906	MBN-14	Surabaya	Kumai	7.472	6.805	206	292.389	0.000638
	MBN-15	Kumai	Surabaya	6.634	9.120	241	291.270	0.000584
1907	MBN-16	Surabaya	Kumai	8.132	7.111	213	291.939	0.000662
	MBN-17	Kumai	Surabaya	6.802	8.074	253	291.490	0.000531
1908	MBN-18	Surabaya	Kumai	9.178	9.382	217	292.678	0.000779
	MBN-19	Kumai	Semarang	11.787	8.891	248	274.480	0.000830
	MBN-20	Semarang	Surabaya	4.513	3.737	37	192.360	0.003145
1909	MBN-21	Surabaya	Kumai	12.084	9.145	215	292.113	0.000924
	MBN-22	Kumai	Semarang	11.457	8.214	260	273.504	0.000759
	MBN-23	Semarang	Surabaya	4.493	3.918	117	193.654	0.001003
1910	MBN-24	Surabaya	Kumai	10.476	10.867	194	293.094	0.001000
	MBN-25	Kumai	Semarang	8.066	7.346	212	273.540	0.000715
	MBN-26	Semarang	Surabaya	4.376	3.311	93	193.512	0.001167

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Table 4. 24 MV Meratus Bontang EEOI Calculation Results

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)		Cargo Carried	Distance Sailed	EEOI (Ton CO2/TEU-nm)
		Origin	Destination	MFO	HSD	TEUs	nm	
1901	MBT-1	Semarang	Pontianak	11.860	10.109	193	469.178	0.000657
	MBT-2	Pontianak	Semarang	10.312	7.267	190	457.570	0.000556
1902	MBT-3	Semarang	Pontianak	12.574	6.576	166	457.130	0.000709
	MBT-4	Pontianak	Semarang	9.811	6.000	195	453.807	0.000496
1903	MBT-5	Semarang	Pontianak	17.535	7.245	130	462.488	0.001177
	MBT-6	Pontianak	Surabaya	11.599	6.234	163	563.294	0.000545

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)		Cargo Carried	Distance Sailed	EEOI (Ton CO2/TEU-nm)
		Origin	Destination	MFO	HSD	TEUs	nm	
1904	MBT-7	Surabaya	Sampit	6.105	8.042	228	297.203	0.000545
	MBT-8	Sampit	Surabaya	5.341	5.682	148	281.035	0.000704
1905	MBT-9	Surabaya	Kumai	6.584	6.180	237	315.977	0.000458
	MBT-10	Kumai	Semarang	6.453	8.045	255	274.125	0.000544
	MBT-11	Semarang	Surabaya	3.379	3.764	247	192.872	0.000397
1906	MBT-12	Surabaya	Sampit	5.887	7.793	309	276.365	0.000418
	MBT-13	Sampit	Surabaya	5.102	6.592	350	276.444	0.000316
1907	MBT-14	Surabaya	Sampit	4.208	6.700	309	278.742	0.000325
	MBT-15	Sampit	Surabaya	5.232	7.419	341	286.247	0.000336
1908	MBT-16	Surabaya	Kumai	6.759	7.913	304	292.484	0.000435
	MBT-17	Kumai	Surabaya	5.341	7.762	220	293.899	0.000525
1909	MBT-18	Surabaya	Semarang	4.382	6.093	255	187.619	0.000569
	MBT-19	Semarang	Kumai	5.320	4.005	291	271.679	0.000322
	MBT-20	Kumai	Surabaya	5.014	6.738	281	295.043	0.000369
1910	MBT-21	Surabaya	Semarang	5.232	12.224	291	190.358	0.000786
	MBT-22	Semarang	Kumai	5.952	3.143	364	272.010	0.000258
	MBT-23	Kumai	Surabaya	5.974	7.323	464	289.680	0.000260

4.4.2. EEOI Calculation with Estimated Fuel Oil Consumption

Calculation of EEOI using the estimated fuel oil consumption is only for the distance sailed during the consumption of MFO, which is distance sailed in cruising mode.

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Table 4. 25 MV Meratus Benoa EEOI Calculation Results using Estimations Methods

Voyage Number	Trip Number	Route		MFO Consumption (Ton)			EEOI During Cruising Mode (Ton CO_2/TEU-nm)		
		Origin	Destination	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.
1901	MBN-1	Surabaya	Kumai	6.853	11.849	6.667	0.000545	0.000942	0.000530
	MBN-2	Kumai	Semarang	7.234	6.810	7.364	0.000553	0.000521	0.000563
	MBN-3	Semarang	Surabaya	5.088	6.457	4.374	0.000733	0.000930	0.000630
1902	MBN-4	Surabaya	Samarinda	13.671	15.156	14.563	0.000480	0.000532	0.000511
	MBN-5	Samarinda	Surabaya	22.821	13.793	15.008	0.000825	0.000499	0.000543
1903	MBN-6	Surabaya	Kumai	12.924	9.843	9.232	0.000634	0.000483	0.000453
	MBN-7	Kumai	Semarang	7.916	7.257	7.912	0.000356	0.000326	0.000356
	MBN-8	Semarang	Surabaya	4.202	5.460	5.299	0.000475	0.000617	0.000599
1904	MBN-9	Surabaya	Sampit	10.948	6.055	7.291	0.000652	0.000361	0.000434
	MBN-10	Sampit	Surabaya	6.882	6.295	5.878	0.000795	0.000727	0.000679
1905	MBN-11	Surabaya	Semarang	5.104	6.382	5.649	0.000513	0.000641	0.000568
	MBN-12	Semarang	Kumai	7.727	7.215	7.555	0.000421	0.000393	0.000412
	MBN-13	Kumai	Surabaya	6.494	6.814	5.508	0.000401	0.000421	0.000340
1906	MBN-14	Surabaya	Kumai	7.472	8.521	7.024	0.000437	0.000498	0.000411

Voyage Number	Trip Number	Route		MFO Consumption (Ton)			EEOI During Cruising Mode (Ton CO_2/TEU-nm)		
		Origin	Destination	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.
1906	MBN-15	Kumai	Surabaya	6.634	7.515	5.664	0.000310	0.000351	0.000265
1907	MBN-16	Surabaya	Kumai	8.132	7.493	7.116	0.000430	0.000396	0.000376
	MBN-17	Kumai	Surabaya	6.802	6.914	6.286	0.000315	0.000320	0.000291
1908	MBN-18	Surabaya	Kumai	9.178	8.093	6.294	0.000467	0.000412	0.000320
	MBN-19	Kumai	Semarang	11.787	6.867	5.672	0.000640	0.000373	0.000308
	MBN-20	Semarang	Surabaya	4.513	4.389	5.049	0.002349	0.002284	0.002628
1909	MBN-21	Surabaya	Kumai	12.084	7.864	8.776	0.000634	0.000413	0.000460
	MBN-22	Kumai	Semarang	11.457	6.692	6.115	0.000526	0.000307	0.000281
	MBN-23	Semarang	Surabaya	4.493	4.581	5.100	0.000785	0.000800	0.000891
1910	MBN-24	Surabaya	Kumai	10.476	7.686	11.527	0.000653	0.000479	0.000719
	MBN-25	Kumai	Semarang	8.066	7.811	6.379	0.000543	0.000526	0.000429
	MBN-26	Semarang	Surabaya	4.376	4.792	4.896	0.000962	0.001053	0.001076

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Table 4. 26 MV Meratus Bontang EEOI Calculation Results using Estimation Methods

Voyage Number	Trip Number	Route		MFO Consumption (Ton)			EEOI During Cruising Mode (Ton CO_2/TEU-nm)		
		Origin	Destination	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.
1901	MBT-1	Semarang	Pontianak	11.860	17.441	12.654	0.000447	0.000966	0.000701
	MBT-2	Pontianak	Semarang	10.312	13.052	10.959	0.000377	0.000703	0.000591
1902	MBT-3	Semarang	Pontianak	12.574	11.784	12.889	0.000519	0.000665	0.000727
	MBT-4	Pontianak	Semarang	9.811	15.595	11.757	0.000352	0.000789	0.000595
1903	MBT-5	Semarang	Pontianak	17.535	11.740	11.608	0.001002	0.000788	0.000779
	MBT-6	Pontianak	Surabaya	11.599	14.669	14.614	0.000422	0.000689	0.000686
1904	MBT-7	Surabaya	Sampit	6.105	6.148	6.496	0.000290	0.000549	0.000580
	MBT-8	Sampit	Surabaya	5.341	6.044	5.736	0.000487	0.000797	0.000756
1905	MBT-9	Surabaya	Kumai	6.584	7.895	6.925	0.000281	0.000549	0.000481
	MBT-10	Kumai	Semarang	6.453	6.267	6.794	0.000331	0.000528	0.000573
	MBT-11	Semarang	Surabaya	3.379	3.659	3.556	0.000409	0.000430	0.000418
1906	MBT-12	Surabaya	Sampit	5.887	5.695	6.264	0.000336	0.000404	0.000445
	MBT-13	Sampit	Surabaya	5.102	5.538	5.479	0.000241	0.000343	0.000339
1907	MBT-14	Surabaya	Sampit	4.208	4.848	4.784	0.000267	0.000375	0.000370
	MBT-15	Sampit	Surabaya	5.232	9.726	5.579	0.000248	0.000625	0.000359
1908	MBT-16	Surabaya	Kumai	6.759	6.502	7.832	0.000348	0.000419	0.000504
	MBT-17	Kumai	Surabaya	5.341	7.630	5.979	0.000471	0.000750	0.000587

Voyage Number	Trip Number	Route		MFO Consumption (Ton)			EEOI During Cruising Mode (Ton CO_2/TEU-nm)		
		Origin	Destination	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.	Actual	Bialystocki and Konovessis	Moreno-Gutiérrez, et al.
1909	MBT-18	Surabaya	Semarang	4.382	4.257	4.694	0.000553	0.000553	0.000609
	MBT-19	Semarang	Kumai	5.320	5.878	6.016	0.000351	0.000356	0.000365
	MBT-20	Kumai	Surabaya	5.014	7.049	6.427	0.000390	0.000519	0.000474
1910	MBT-21	Surabaya	Semarang	5.232	5.284	2.802	0.000466	0.000794	0.000421
	MBT-22	Semarang	Kumai	5.952	6.174	6.731	0.000637	0.000268	0.000292
	MBT-23	Kumai	Surabaya	5.974	7.158	6.687	0.000323	0.000311	0.000291

4.5. Analysis of EEOI Calculation

4.5.1. Analysis of EEOI per Voyage Route

Analysis of EEOI of MV Meratus Benoa and MV Meratus Bontang is done using the same voyage route which could be assumed to have relatively same sailing distance. Therefore, factors that influence the result of EEOI could be determined.

a. Route Semarang – Surabaya

MV Meratus Benoa

Table 4. 27 MV Meratus Benoa Route Semarang – Surabaya EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1901	MBN-3	Semarang	Surabaya	5.088	3.344	8.432	9.19	147	0.000821
1903	MBN-8	Semarang	Surabaya	4.202	2.744	6.946	8.32	163	0.000618
1908	MBN-20	Semarang	Surabaya	4.513	3.737	8.250	7.68	37	0.003145
1909	MBN-23	Semarang	Surabaya	4.493	3.918	8.412	7.94	117	0.001003
1910	MBN-26	Semarang	Surabaya	4.376	3.311	7.687	8.23	93	0.001167
1905	MBN-11	Surabaya	Semarang	5.104	9.693	14.796	8.57	178	0.001099
					Average	**9.087**	**8.32**	**123**	

Average EEOI of MV Meratus Benoa for the voyage with route Semarang – Surabaya is **0.001309 ton CO_2/TEU-nm**.

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Table 4. 28 MV Meratus Bontang Route Semarang – Surabaya EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1905	MBT-11	Semarang	Surabaya	3.379	3.764	7.143	8.05	247	0.000397
1909	MBT-18	Surabaya	Semarang	4.382	6.093	10.475	7.04	255	0.000569
1910	MBT-21	Surabaya	Semarang	5.232	12.224	17.457	9.59	291	0.000786
					Average	**11.692**	**8.22**	**264**	

Average EEOI of MV Meratus Bontang for the voyage with route Semarang – Surabaya is **0.000584 ton CO_2/TEU-nm**.

b. Route Surabaya – Sampit

MV Meratus Benoa

Table 4. 29 MV Meratus Benoa Route Surabaya – Sampit EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1904	MBN-9	Surabaya	Sampit	10.948	8.195	19.143	7.38	215	0.000847
1904	MBN-10	Sampit	Surabaya	6.882	8.134	15.015	7.61	112	0.001235
					Average	**17.079**	**7.49**	**164**	

Average EEOI of MV Meratus Benoa for the voyage with route Surabaya – Sampit is **0.001041 ton CO_2/TEU-nm**.

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Table 4. 30 MV Meratus Bontang Route Surabaya – Sampit EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1904	MBT-7	Surabaya	Sampit	6.105	8.042	14.147	7.74	228	0.000545
1906	MBT-12	Surabaya	Sampit	5.887	7.793	13.680	7.09	309	0.000418
1907	MBT-14	Surabaya	Sampit	4.208	6.700	10.908	8.25	309	0.000325
1904	MBT-8	Sampit	Surabaya	5.341	5.682	11.023	8.19	148	0.000704
1906	MBT-13	Sampit	Surabaya	5.102	6.592	11.694	8.06	350	0.000316
1907	MBT-15	Sampit	Surabaya	5.232	7.419	12.652	9.40	341	0.000336
					Average	**12.351**	**8.12**	**281**	

Average EEOI of MV Meratus Bontang for the voyage with route Surabaya – Sampit is **0.000441 ton CO_2/TEU-nm**.

c. Route Semarang – Kumai

MV Meratus Benoa

Table 4. 31 MV Meratus Benoa Route Semarang – Kumai EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1901	MBN-2	Kumai	Semarang	7.234	9.139	16.374	7.53	198	0.000797
1903	MBN-7	Kumai	Semarang	7.916	8.432	16.348	7.09	268	0.000590
1908	MBN-19	Kumai	Semarang	11.787	8.891	20.678	7.70	248	0.000830
1909	MBN-22	Kumai	Semarang	11.457	8.214	19.671	7.87	260	0.000759
1910	MBN-25	Kumai	Semarang	8.066	7.346	15.412	6.73	212	0.000715
1905	MBN-12	Semarang	Kumai	7.727	2.822	10.549	8.24	221	0.000496
					Average	**16.505**	**7.53**	**235**	

Average EEOI of MV Meratus Benoa for the voyage with route Semarang – Kumai is **0.000698 ton CO_2/TEU-nm**.

MV Meratus Bontang

Table 4. 32 MV Meratus Bontang Route Semarang – Kumai EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1905	MBT-10	Kumai	Semarang	6.453	8.045	14.498	7.48	255	0.000544
1909	MBT-19	Semarang	Kumai	5.320	4.005	9.325	8.12	291	0.000322
1910	MBT-22	Semarang	Kumai	5.952	3.143	9.095	7.88	364	0.000258
					Average	**10.973**	**7.83**	**303**	

Average EEOI of MV Meratus Bontang for the voyage with route Semarang – Kumai is **0.000375 ton CO_2/TEU-nm**.

d. Route Surabaya – Kumai

MV Meratus Benoa

Table 4. 33 MV Meratus Benoa Route Surabaya – Kumai EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1901	MBN-1	Surabaya	Kumai	6.853	8.386	15.239	9.11	162	0.000836
1903	MBN-6	Surabaya	Kumai	12.924	11.168	24.092	7.63	221	0.001002
1906	MBN-14	Surabaya	Kumai	7.472	6.805	14.277	6.64	206	0.000638
1907	MBN-16	Surabaya	Kumai	8.132	7.111	15.243	7.08	213	0.000662
1908	MBN-18	Surabaya	Kumai	9.178	9.382	18.560	8.32	217	0.000779
1909	MBN-21	Surabaya	Kumai	12.084	9.145	21.230	8.66	215	0.000924
1910	MBN-24	Surabaya	Kumai	10.476	10.867	21.343	6.81	194	0.001000
1905	MBN-13	Kumai	Surabaya	6.494	7.679	14.174	7.87	174	0.000733
1906	MBN-15	Kumai	Surabaya	6.634	9.120	15.754	8.15	241	0.000584
1907	MBN-17	Kumai	Surabaya	6.802	8.074	14.877	7.79	253	0.000531
					Average	**17.479**	**7.81**	**210**	

Average EEOI of MV Meratus Bontang for the voyage with route Surabaya – Kumai is **0.000409 ton CO_2/TEU-nm**.

MV Meratus Bontang

Table 4. 34 MV Meratus Bontang Route Surabaya – Kumai EEOI

Voyage Number	Trip Number	Route		Fuel Oil Consumption (Ton)			Avg. Vs (Knot)	TEUs	EEOI
		Origin	Destination	MFO	HSD	Total			
1908	MBT-17	Kumai	Surabaya	5.341	7.762	13.104	8.81	220	0.000525
1910	MBT-23	Kumai	Surabaya	5.974	7.323	13.297	8.36	464	0.000260
1909	MBT-20	Kumai	Surabaya	5.014	6.738	11.753	8.77	281	0.000369
1905	MBT-9	Surabaya	Kumai	6.584	6.180	12.764	8.36	237	0.000458
1908	MBT-16	Surabaya	Kumai	6.759	7.913	14.671	7.30	304	0.000435
					Average	**13.118**	**8.32**	**301**	

Average EEOI of MV Meratus Benoa for the voyage with route Surabaya – Kumai is **0.000769 ton CO_2/TEU-nm**.

e. Voyage Route Analysis

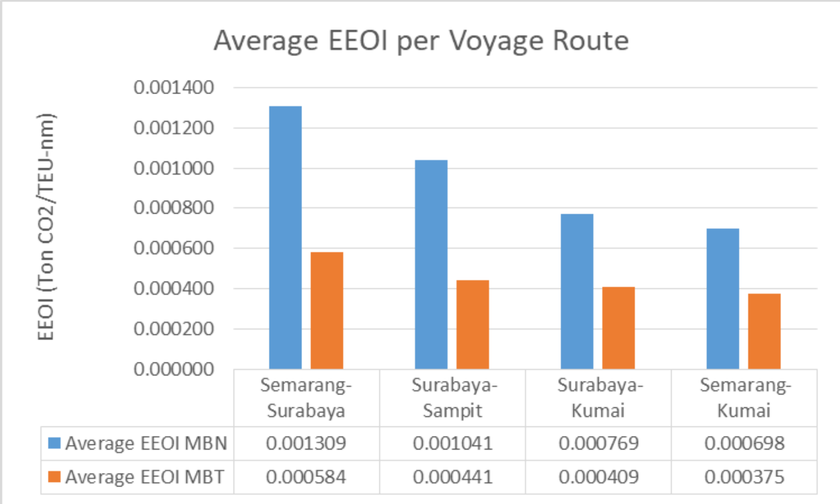

Figure 4. 5 Graph of Average EEOI per Voyage Route

Figure 4.5 shows that MV Meratus Benoa has higher average EEOI than MV Meratus Bontang. Factors that influence the EEOI result could be described using formula (23), which is a function of fuel oil consumption, distance sailed, and the amount of cargo carried. The distance factor then could be neglected because of the same voyage route and relatively same sailed distance. Then, fuel oil consumption and the amount of cargo carried are the remaining variables that affect the result of EEOI.

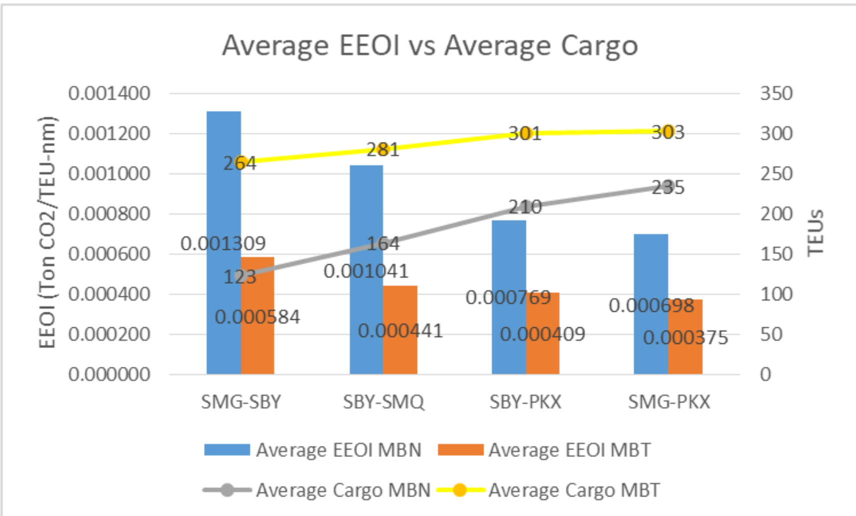

Figure 4. 6 Graph of Average EEOI and Average Cargo

From figure 4.6, it could be analyzed that for route Semarang – Surabaya MV Meratus Benoa has average cargo carried of **123** TEUs with average EEOI of **0.001309** and MV Meratus Bontang has average cargo carried of **264** TEUs with average EEOI of **0.000584 ton CO_2/TEU-nm**. For route Surabaya – Sampit, MV Meratus Benoa has average cargo carried of **164** TEUs with average EEOI of **0.001401 ton CO_2/TEU-nm** and MV Meratus Bontang has average cargo carried of **281** TEUs with average EEOI of **0.000441 ton CO_2/TEU-nm**. For route Semarang – Kumai, MV Meratus Benoa has average cargo carried of **235** TEUs with average EEOI of **0.000698 ton CO_2/TEU-nm** and MV Meratus Bontang has average cargo carried of **303** TEUs with average EEOI of **0.000375 ton CO_2/TEU-nm**. For route Surabaya – Kumai, MV Meratus Benoa has average cargo carried of **210** TEUs with average EEOI of **0.000769 ton CO_2/TEU-nm** and MV Meratus Bontang has average cargo carried of **301** TEUs with average EEOI of **0.000409 ton CO_2/TEU-nm**.

MV Meratus Benoa has the highest average of EEOI at route Semarang – Surabaya and the lowest at Semarang – Kumai. At highest average of EEOI (route Surabaya – Semarang), MV Meratus Benoa carried the lowest average of cargo carried. While the lowest average of EEOI (route Semarang – Kumai), MV Meratus Benoa carried the highest average of cargo carried.

MV Meratus Bontang has the highest average of EEOI at route Semarang – Surabaya and the lowest at Semarang – Kumai. At highest average of EEOI (route Surabaya – Semarang), MV Meratus Bontang carried the lowest average of cargo carried. While the lowest average of EEOI (route Semarang – Kumai), MV Meratus Bontang carried the highest average of cargo carried.

In terms of cargo carried, MV Meratus Bontang has lower average EEOI in those four routes than MV Meratus Benoa, because the amount of cargo carried by MV Meratus Bontang is averagely higher than MV Meratus Benoa.

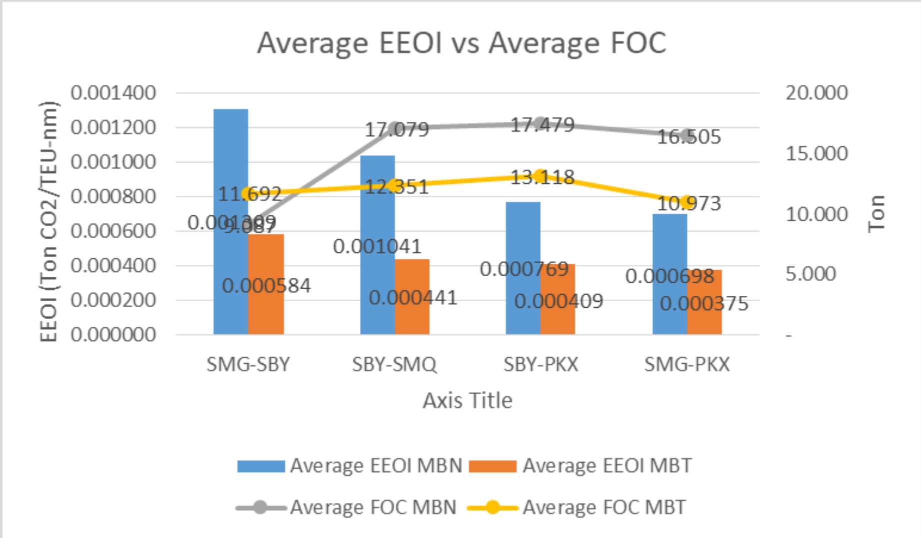

Figure 4. 7 Graph of Average EEOI and Average Fuel Oil Consumption

Figure 4.7 shows the relation between average EEOI and average fuel oil consumption per voyage route. At route Semarang – Surabaya, MV Meratus Benoa has average fuel oil consumption of **9.087 ton** with average EEOI of **0.001309 ton CO_2/TEU-nm** and MV Meratus Bontang has average fuel oil consumption of **11.692 ton** with average EEOI of **0.000584 ton CO_2/TEU-nm**. At route Surabaya – Sampit, MV Meratus Benoa has average fuel oil consumption of **17.079 ton** with average EEOI of **0.001401 ton CO_2/TEU-nm** and MV Meratus Bontang has average fuel oil consumption of **12.351 ton** with average EEOI of **0.000441 ton CO_2/TEU-nm**. At route Surabaya – Kumai, MV Meratus Benoa has average fuel oil consumption of **17.479 ton** with average EEOI of **0.000769 ton CO_2/TEU-nm** and MV Meratus Bontang has average fuel oil consumption of **13.118 ton** with average EEOI of **0.000409 ton CO_2/TEU-nm**. At route Semarang – Kumai, MV Meratus Benoa has average fuel oil consumption of **16.505 ton** with average EEOI of **0.000698 ton CO_2/TEU-nm** and MV Meratus Bontang has average fuel oil consumption of **10.973 ton** with average EEOI of **0.000375 ton CO_2/TEU-nm**.

MV Meratus Benoa has a higher average of fuel oil consumption than MV Meratus Bontang as shown in Figure 4.7. Therefore, the average value of EEOI for MV Meratus Bontang is lower than MV Meratus Benoa.

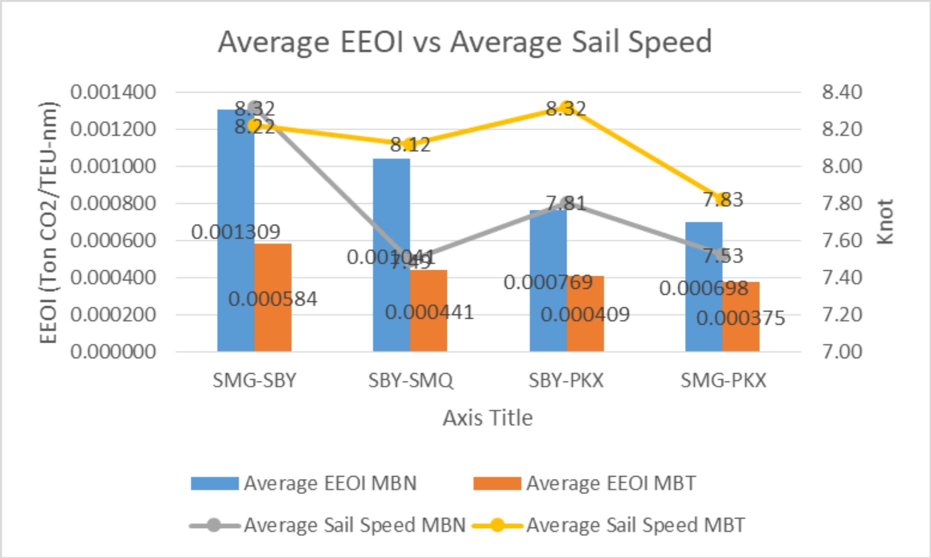

Figure 4. 8 Graph of Average EEOI and Average Sail Speed

EEOI is a function of fuel oil consumption, distance sailed, and the amount of cargo carried. Fuel oil consumption is a function of power, while power is a function of the ship's resistance and ship's speed. Thus, it could be said that higher operational speed produces higher resistance to the ship, hence higher speed would result in higher fuel oil consumption.

It could be analyzed from figure 4.8 that MV Meratus Bontang operated at a higher average speed than MV Meratus Benoa. Although fuel oil consumption is not the only factor that influences the result of EEOI, it could be seen that lower average speed results in lower average EEOI.

4.5.2. Analysis of Overall EEOI

a. MV Meratus Benoa

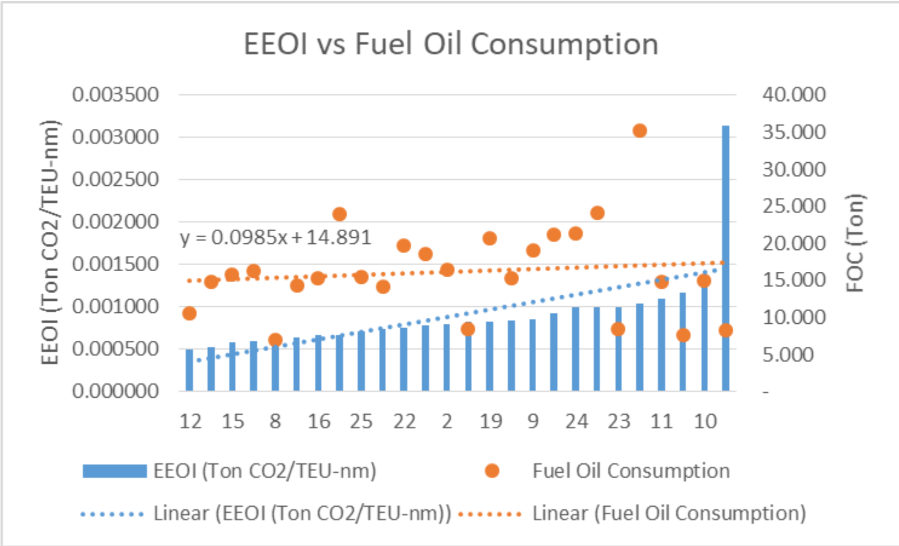

Figure 4. 9 Graph of MV Meratus Benoa EEOI and Fuel Oil Consumption

Figure 4.9 shows the relation between EEOI and fuel oil consumption of MV Meratus Benoa. Value of EEOI is sorted from the lowest to the highest. As shown in the graph, the trend line of fuel oil consumption has a positive gradient and increases insignificantly.

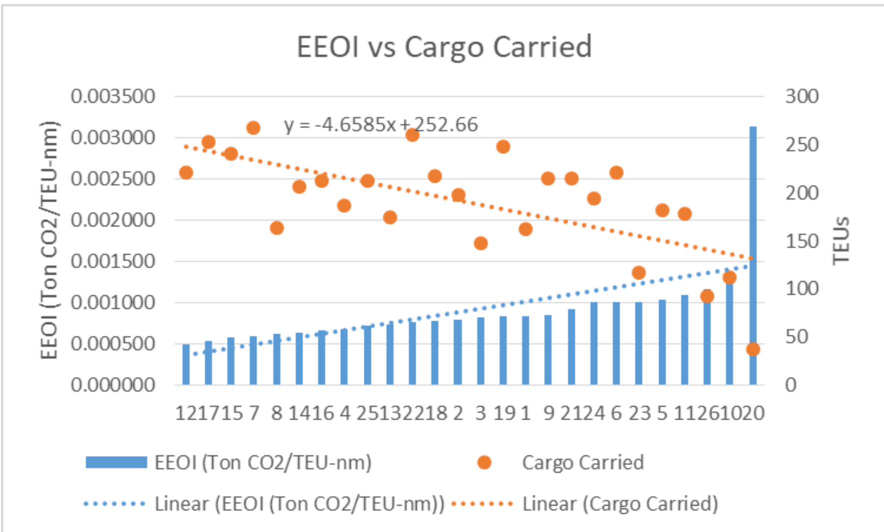

Figure 4. 10 Graph of MV Meratus Benoa EEOI and Cargo Carried

Figure 4.10 shows the correlation between EEOI and amount of cargo carried by MV Meratus Benoa. Analyzed from the graph, it shows the different relationship between these variables. Value of EEOI increases as the amount of cargo carried decreased significantly. This is shown by a negative gradient of the trend line.

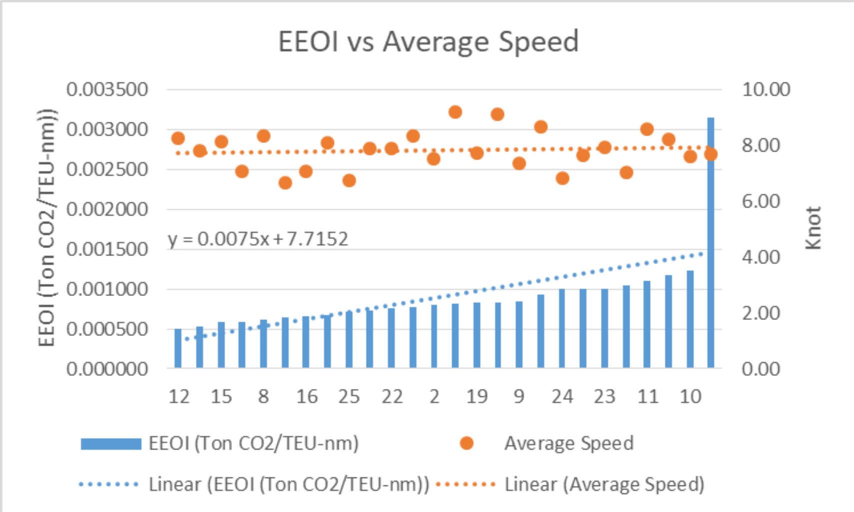

Figure 4. 11 Graph of MV Meratus Benoa EEOI and Average Speed

Figure 4.11 represents the relation between EEOI of MV Meratus Benoa and average speed of the ship. The trend line of average speed shows a slight increase with a positive gradient. The graph shows that the average speed of the ship does not have significant increase correlated with the value of EEOI that increases dramatically.

b. MV Meratus Bontang

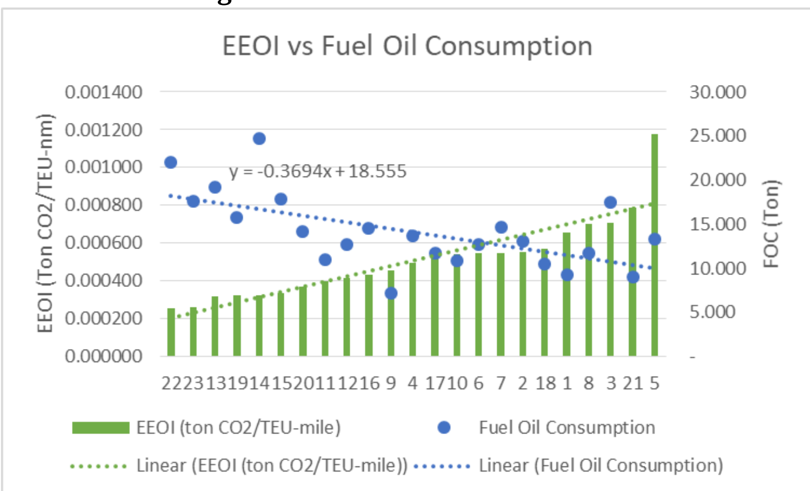

Figure 4. 12 Graph of MV Meratus Bontang EEOI and Fuel Oil Consumption

Correlation between EEOI of MV Meratus Bontang and its fuel oil consumption is represented in figure 4.12. The trend line indicates a positive gradient. The graph shows the increase in EEOI when the trend line of fuel oil consumption increases significantly.

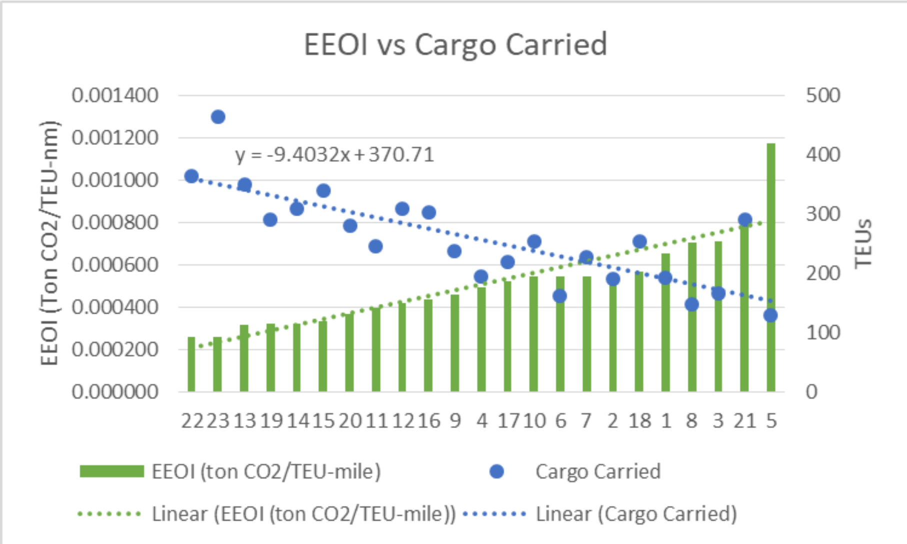

Figure 4. 13 Graph of MV Meratus Bontang EEOI and Cargo Carried

Figure 4.13 shows the relation between the EEOI of MV Meratus Benoa and the amount of cargo it carried. The connection between EEOI and cargo carried is inversely proportional. The trend line has a negative gradient that indicates significant decrease when EEOI increases.

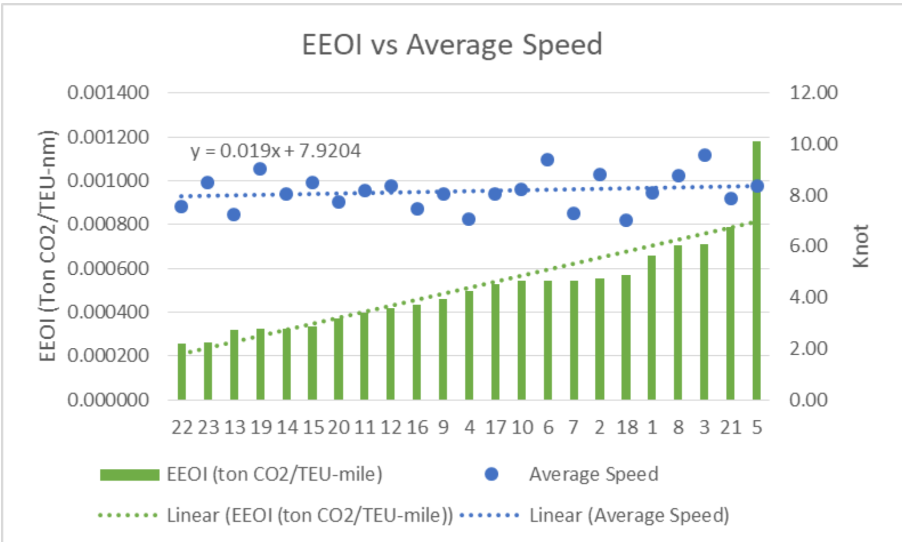

Figure 4. 14 Graph of MV Meratus Bontang EEOI and Average Speed

Figure 4.14 shows a correlation between the EEOI of MV Meratus Benoa and its average sailing speed. The trend line shows a slight decrease with a negative gradient. This shows that EEOI increases while the average speed decreases slightly. It could be concluded that the sailing speed of MV Meratus Bontang does not influence the value of EEOI.

Chapter V
Conclusion

5.1. .Conclusion

The conclusion from this research are:

1. Estimation of fuel oil consumption resulted in fuel estimation per voyage trip. The results are compared with actual fuel oil consumption, and the calculation of error resulted as follow:
   a. Bialystocki and Konovessis' Method
      - MV Meratus Benoa : 19.958%
      - MV Meratus Bontang : 20.926%
      - Overall Average : 20.442%

   b. Moreno-Gutiérrez, et al.'s Method
      - MV Meratus Benoa : 17.550%
      - MV Meratus Bontang : 13.320%
      - Overall Average : 15.450%

2. Energy Efficiency Operational Indicator (EEOI) calculation resulted as follow:
   - MV Meratus Benoa

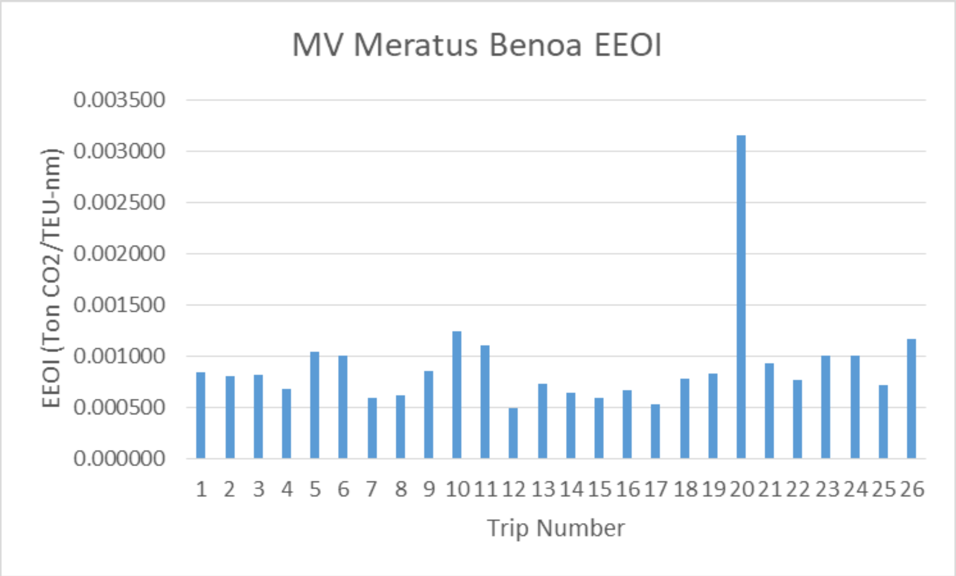

Figure 5. 1 MV Meratus Benoa EEOI

Average EEOI of MV Meratus Benoa is **0.000905 ton CO_2/TEU-nm.**

- MV Meratus Bontang

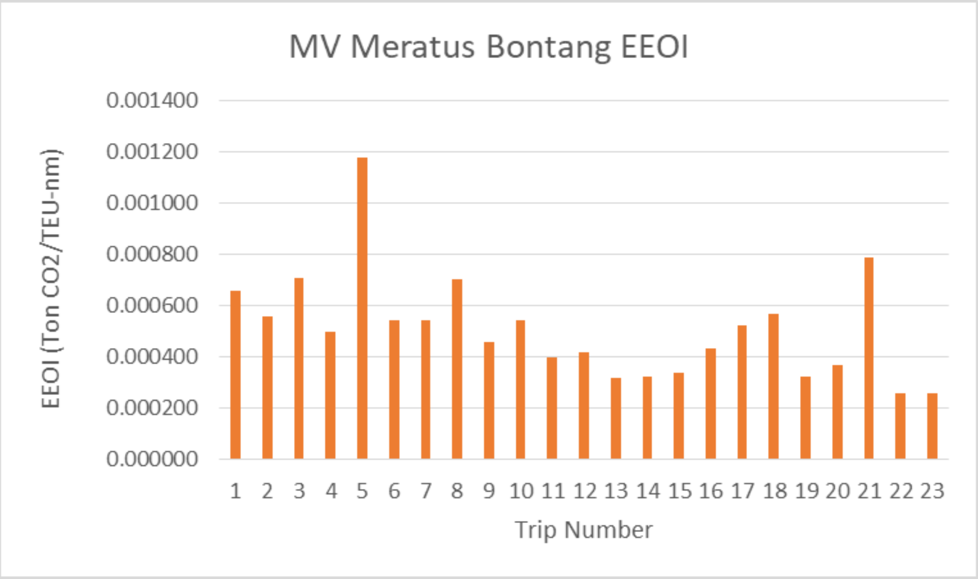

Figure 5. 2 MV Meratus Bontang EEOI

Average EEOI of MV Meratus Bontang is **0.000509 ton CO_2/TEU-nm.**

3. The benchmarking process is done by comparing the results of EEOI between MV Meratus Benoa and MV Meratus Bontang. As the base of benchmarking, one variable is assumed to be relatively same which is the distance sailed. The same voyage route of both MV Meratus Benoa and MV Meratus Bontang then chosen to be the base assumption for figuring out the relation between variables.
   The variables that directly influence the result of EEOI are fuel oil consumption and the amount of cargo carried. Other variables that indirectly affect the EEOI result are ship speed and wetted surface area.
   Benchmarking process of EEOI resulted as follow:
   1. From the analysis of 10 voyages with the same time range, MV Meratus Bontang is more efficient than MV Meratus Benoa. This could be concluded from the average EEOI of MV Meratus Bontang which is 56% lower than EEOI of MV Meratus Benoa.
   2. Analysis of EEOI for the same voyage route of both ships resulted in a higher average of EEOI for MV Meratus Benoa than MV Meratus Bontang, which is shown as follow:
      - EEOI of MV Meratus Benoa for voyage route Semarang – Surabaya is **0.001309 ton CO_2/TEU-nm**, for voyage route Surabaya – Sampit is **0.000441 ton CO_2/TEU-nm**, for voyage

route Semarang – Kumai is **0.000698 ton CO_2/TEU-nm**, and for voyage route Surabaya – Kumai is **0.000769 ton CO_2/TEU-nm.**

- EEOI of MV Meratus Bontang for voyage route Semarang – Surabaya is **0.000584 ton CO_2/TEU-nm,** for voyage route Surabaya – Sampit is **0.001041 ton CO2/TEU-nm**, for voyage route Semarang – Kumai is **0.000375 ton CO_2/TEU-nm**, and for voyage route Surabaya – Kumai is **0.000409 ton CO_2/TEU-nm.**

3. In terms of cargo, MV Meratus Bontang has a higher average of cargo carried than MV Meratus Benoa. This is shown as follow:
   - Route Semarang – Surabaya
     - MV Meratus Bontang : 264 TEUs
     - MV Meratus Benoa : 123 TEUs
   - Route Surabaya – Sampit
     - MV Meratus Bontang : 281 TEUs
     - MV Meratus Benoa : 164 TEUs
   - Route Semarang – Kumai
     - MV Meratus Bontang : 303 TEUs
     - MV Meratus Benoa : 235 TEUs
   - Route Surabaya – Kumai
     - MV Meratus Bontang : 301 TEUs
     - MV Meratus Benoa : 210 TEUs
4. For average fuel oil consumption, 3 out of 4 voyage route shows that MV Meratus Benoa has a higher average of fuel oil consumption than MV Meratus Bontang. This is described as follow:
   - Route Semarang – Surabaya
     - MV Meratus Bontang : 11.692 Ton
     - MV Meratus Benoa : 9.087 Ton
   - Route Surabaya – Sampit
     - MV Meratus Bontang : 12.351 Ton
     - MV Meratus Benoa : 17.079 Ton
   - Route Semarang – Kumai
     - MV Meratus Bontang : 10.973 Ton
     - MV Meratus Benoa : 16.505 Ton
   - Route Surabaya – Kumai
     - MV Meratus Bontang : 13.118 Ton
     - MV Meratus Benoa : 17.479 Ton
5. For average sailing speed, MV Meratus Bontang operated at higher average speed than MV Meratus Benoa.
   - Route Semarang – Surabaya
     - MV Meratus Bontang : 8.22 Knot
     - MV Meratus Benoa : 8.32 Knot
   - Route Surabaya – Sampit

   - MV Meratus Bontang : 8.12 Knot
   - MV Meratus Benoa : 7.49 Knot
- Route Semarang – Kumai
   - MV Meratus Bontang : 7.83 Knot
   - MV Meratus Benoa : 7.53 Knot
- Route Surabaya – Kumai
   - MV Meratus Bontang : 8.32 Knot
   - MV Meratus Benoa : 7.81 Knot

4. Based on the benchmarking result between both ships, possible improvement for the ships could be proposed. Improvement of cargo management could be made particularly for MV Meratus Benoa which has less average cargo carried compared to MV Meratus Bontang. In terms of ship operational condition, ship operators of both ships should monitor and evaluate which operational mode suits the best against the sea condition at that specific time.

5.2. Suggestion

Based on the result of this research, some suggestions are given by author to support further research are as follow:

1. For Bialystocki and Konovessis's method of fuel oil consumption estimation, author suggests more comprehend data collection with longer time range more than three months of ship's noon report for better accuracy towards the fuel oil consumption estimation.
2. For Moreno-Gutiérrez, et al.'s method of fuel oil consumption estimation, author suggests further research data specifically for the ship's main engine power during the sea voyage.
3. For further research which suggest improvement using EEOI as a tool for monitoring, it is necessary to have better comprehension about factors that influence the ship activity during its voyage and how the ship operators operates the ship in specific sea condition.

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APPENDIX

ATTACHMENT 1:

FUEL OIL CONSUMPTION ESTIMATION
(Bialystocki and Konovessis)

Noon Report of MV Meratus Benoa

Voyage Number	Trip Number	Route		Noon Report Date	Ship's Course	Weather Direction
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	09/01/2019	342	North West
	MBN-2	Kumai	Semarang	13/01/2019	199	South West
	MBN-3	Semarang	Surabaya	14/01/2019	79	South East
1902	MBN-4	Surabaya	Samarinda	17/01/2019	Unnoted	
				18/01/2019	55	North West
				19/01/2019	12	North West
	MBN-5	Samarinda	Surabaya	22/01/2019	208	South
				23/01/2019	195	South
				24/01/2019	235	South West
1903	MBN-6	Surabaya	Kumai	28/01/2019	342	West
	MBN-7	Kumai	Semarang	01/02/2019	199	South West
	MBN-8	Semarang	Surabaya	03/02/2019	Unnoted	
1904	MBN-9	Surabaya	Sampit	05/02/2019	54	West
				06/02/2019	0	North West
	MBN-10	Sampit	Surabaya	08/02/2019	180	West
1905	MBN-11	Surabaya	Semarang	Unnoted		
	MBN-12	Semarang	Kumai	12/02/2019	19	North
				13/02/2019	8	North West
	MBN-13	Kumai	Surabaya	15/02/2019	160	South East
1906	MBN-14	Surabaya	Kumai	18/02/2019	340	North West
	MBN-15	Kumai	Surabaya	21/02/2019	160	North West
1907	MBN-16	Surabaya	Kumai	Unnoted		
	MBN-17	Kumai	Surabaya	27/02/2019	160	South East
1908	MBN-18	Surabaya	Kumai	03/03/2019	342	North West
	MBN-19	Kumai	Semarang	07/03/2019	199	South West
	MBN-20	Semarang	Surabaya	Unnoted		
1909	MBN-21	Surabaya	Kumai	14/03/2019	7	North West
	MBN-22	Kumai	Semarang	17/03/2019	200	South West
	MBN-23	Semarang	Surabaya	Unnoted		
1910	MBN-24	Surabaya	Kumai	Unnoted		
	MBN-25	Kumai	Semarang	26/03/2019	200	South
				27/03/2019	200	South
	MBN-26	Semarang	Surabaya	28/03/2019	104	North East

Voyage Number	Trip Number	Weather Force	Steaming Time (Hour)	Travelled Distance (nm)	Ground Speed	Engine Speed
1901	MBN-1	1	15.6	113	7.26	600
	MBN-2	3	22.6	164	7.25	630
	MBN-3	2	5.2	45	8.65	630
1902	MBN-4	Unnoted				
		2	24	191	7.95	630
		2	23	160	6.95	630
	MBN-5	1	2	16	8.00	580
		4	24	168	7.00	580
		4	25	186	7.44	630
1903	MBN-6	4	21.9	111	5.06	580
	MBN-7	2	20.4	146	7.15	630
	MBN-8	Unnoted				
1904	MBN-9	2	3.1	25	8.01	620
		2	24	193	8.04	630
	MBN-10	2	16.7	133	7.96	600
1905	MBN-11	Unnoted				
	MBN-12	1	2.5	18.5	7.40	630
		3	24	195.5	8.08	630
	MBN-13	3	9.2	69.5	7.55	580
1906	MBN-14	3	17.2	105	6.10	580
	MBN-15	1	9.6	72	7.83	580
1907	MBN-16	Unnoted				
	MBN-17	3	9.3	69	7.41	600
1908	MBN-18	1	1.2	8	6.60	600
	MBN-19	4	11	76	6.90	580
	MBN-20	Unnoted				
1909	MBN-21	1	24	214	8.92	600
	MBN-22	3	22.7	176	7.75	600
	MBN-23	Unnoted				
1910	MBN-24	Unnoted				
	MBN-25	1	10.5	70	6.66	580
		1	24	162	6.83	580
	MBN-26	1	7.6	68	8.94	620

Voyage Number	Trip Number	FOC MFO (Liter)	Draft (Meter)		Displacement (Ton)
			Fore	Aft	
1901	MBN-1	3352	3.4	4.2	6245.32
	MBN-2	5149	3.9	4.1	6842.16
	MBN-3	1144	1.8	3.5	4511.92
1902	MBN-4				
		5280	4	4.2	7184.36
		5060	4	4.2	7184.36
	MBN-5	440	3.6	3.8	6463.20
		5208	3.6	3.8	6463.20
		10780	3.6	3.8	6463.20
1903	MBN-6	7921	4.2	4.5	7524.32
	MBN-7	4488	4	4.5	7320.72
	MBN-8				
1904	MBN-9	682	3.9	4.2	7560.32
		9700	3.9	4.2	7560.32
	MBN-10	3674	1.8	3.4	4577.00
1905	MBN-11				
	MBN-12	575	4.3	4.4	7427.02
		6130	4.3	4.4	7427.02
	MBN-13	2070	3.4	4	6271.56
1906	MBN-14	3440	4.2	4.5	7470.62
	MBN-15	2016	2.6	3.8	5225.10
1907	MBN-16				
	MBN-17	2046	3.9	4.1	6728.14
1908	MBN-18	506	4.25	4.5	7493.48
	MBN-19	2387	3.85	4.5	7120.00
	MBN-20				
1909	MBN-21	10920	4.5	4.7	8038.00
	MBN-22	8371	3.3	4.2	6088.99
	MBN-23				
1910	MBN-24				
	MBN-25	2362	2.8	4.4	5889.77
		5400	2.8	4.4	5889.77
	MBN-26	1748	1.9	3.5	4271.60

Voyage Nun	Trip Number	Route		Noon Report Date	Ship's Course (Degree)	Weather/Wind Direction (Compass)
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	09/01/2019	342	North West
	MBN-2	Kumai	Semarang	13/01/2019	199	South West
	MBN-3	Semarang	Surabaya	14/01/2019	79	South East
1902	MBN-4	Surabaya	Samarinda	17/01/2019		
				18/01/2019	55	North West
				19/01/2019	12	North West
	MBN-5	Samarinda	Surabaya	22/01/2019	208	South
				23/01/2019	195	South
				24/01/2019	235	South West
1903	MBN-6	Surabaya	Kumai	28/01/2019	342	West
	MBN-7	Kumai	Semarang	01/02/2019	199	South West
	MBN-8	Semarang	Surabaya	03/02/2019		
1904	MBN-9	Surabaya	Sampit	05/02/2019	54	West
				06/02/2019	0	North West
	MBN-10	Sampit	Surabaya	08/02/2019	180	West
1905	MBN-11	Surabaya	Semarang			
	MBN-12	Semarang	Kumai	12/02/2019	19	North
				13/02/2019	8	North West
	MBN-13	Kumai	Surabaya	15/02/2019	160	South East
1906	MBN-14	Surabaya	Kumai	18/02/2019	340	North West
	MBN-15	Kumai	Surabaya	21/02/2019	160	North West
1907	MBN-16	Surabaya	Kumai			
	MBN-17	Kumai	Surabaya	27/02/2019	160	South East
1908	MBN-18	Surabaya	Kumai	03/03/2019	342	North West
	MBN-19	Kumai	Semarang	07/03/2019	199	South West
	MBN-20	Semarang	Surabaya			
1909	MBN-21	Surabaya	Kumai	14/03/2019	7	North West
	MBN-22	Kumai	Semarang	17/03/2019	200	South West
	MBN-23	Semarang	Surabaya			
1910	MBN-24	Surabaya	Kumai			
	MBN-25	Kumai	Semarang	26/03/2019	200	South
				27/03/2019	200	South
	MBN-26	Semarang	Surabaya	28/03/2019	104	North East

Preliminary Step of Fuel Oil Consumption Estimation

Step 1: Corection of fuel oil consumption to the steaming time

$$\text{Fuel Cons}_{\text{Corr}} = 24 \times \frac{\text{Fuel Cons}_{\text{Recorded}}}{\text{Steaming Time}}$$

Voyage Number	Trip Number	Route		Steaming Time (Hour)	FOC MFO (liter)	Fuel Cons Corr
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	15.6	3,352	5,156.9
	MBN-2	Kumai	Semarang	22.6	5,149	5,468.0
	MBN-3	Semarang	Surabaya	5.2	1,144	5,280.0
1902	MBN-4	Surabaya	Samarinda	Unnoted		
				24.0	5,280	5,280.0
				23.0	5,060	5,280.0
	MBN-5	Samarinda	Surabaya	2.0	440	5,280.0
				24.0	5,208	5,208.0
				25.0	10,780	10,348.8
1903	MBN-6	Surabaya	Kumai	21.9	7,921	8,680.5
	MBN-7	Kumai	Semarang	20.4	4,488	5,280.0
	MBN-8	Semarang	Surabaya	Unnoted		
1904	MBN-9	Surabaya	Sampit	3.1	682	5,280.0
				24.0	9,700	9,700.0
	MBN-10	Sampit	Surabaya	16.7	3,674	5,280.0
1905	MBN-11	Surabaya	Semarang	Unnoted		
	MBN-12	Semarang	Kumai	2.5	575	5,520.0
				24.0	6,130	6,130.0
	MBN-13	Kumai	Surabaya	9.2	2,070	5,400.0
1906	MBN-14	Surabaya	Kumai	17.2	3,440	4,800.0
	MBN-15	Kumai	Surabaya	9.6	2,016	5,040.0
1907	MBN-16	Surabaya	Kumai	Unnoted		
	MBN-17	Kumai	Surabaya	9.3	2,046	5,280.0
1908	MBN-18	Surabaya	Kumai	1.2	506	10,120.0
	MBN-19	Kumai	Semarang	11.0	2,387	5,208.0
	MBN-20	Semarang	Surabaya	Unnoted		
1909	MBN-21	Surabaya	Kumai	24.0	10,920	10,920.0
	MBN-22	Kumai	Semarang	22.7	8,371	8,850.4
	MBN-23	Semarang	Surabaya	Unnoted		

1910	MBN-24	Surabaya	Kumai	Unnoted		
	MBN-25	Kumai	Semarang	10.5	2,362	5,398.9
				24.0	5,400	5,400.0
	MBN-26	Semarang	Surabaya	7.6	1,748	5,520.0

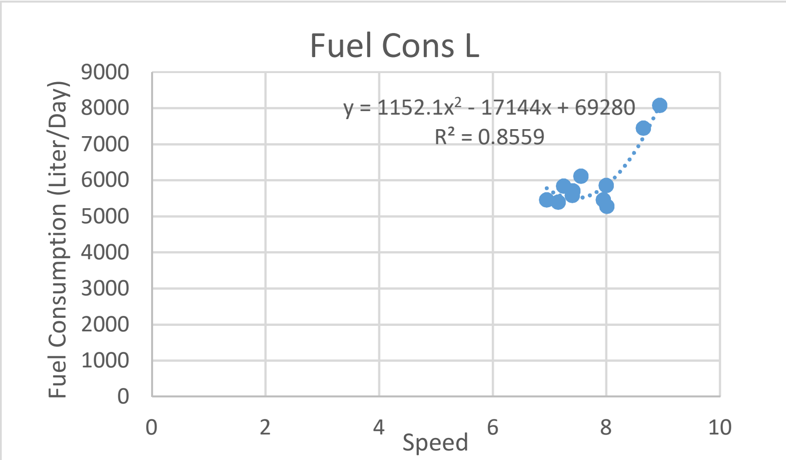
Step 2: Corection of fuel oil consumption to ship's diplacement

$$\text{Fuel Cons}_{L} = \text{Fuel Cons}_{Corr} \times \left(\frac{\text{Disp}_{Load}}{\text{Disp}_{Corr}} \right)^{2/3}$$

Voyage Number	Trip Number	Route		Displacement (Ton)	Fuel Cons Corr	Fuel Cons L
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	6,245.32	5,156.92	5,857.88
	MBN-2	Kumai	Semarang	6,842.16	5,467.96	5,844.53
	MBN-3	Semarang	Surabaya	4,511.92	5,280.00	7,449.25
1902	MBN-4	Surabaya	Samarinda	Unnoted		
				7,184.36	5,280.00	5,462.96
				7,184.36	5,280.00	5,462.96
	MBN-5	Samarinda	Surabaya	6,463.20	5,280.00	5,862.12
				6,463.20	5,208.00	5,782.19
				6,463.20	10,348.80	11,489.76
1903	MBN-6	Surabaya	Kumai	7,524.32	8,680.55	8,708.74
	MBN-7	Kumai	Semarang	7,320.72	5,280.00	5,394.91
	MBN-8	Semarang	Surabaya	Unnoted		
1904	MBN-9	Surabaya	Sampit	7,560.32	5,280.00	5,280.32
				7,560.32	9,700.00	9,700.58
	MBN-10	Sampit	Surabaya	4,577.00	5,280.00	7,378.47
1905	MBN-11	Surabaya	Semarang	Unnoted		
	MBN-12	Semarang	Kumai	7,427.02	5,520.00	5,586.19
				7,427.02	6,130.00	6,203.50
	MBN-13	Kumai	Surabaya	6,271.56	5,400.00	6,116.87
1906	MBN-14	Surabaya	Kumai	7,470.62	4,800.00	4,838.64
	MBN-15	Kumai	Surabaya	5,225.10	5,040.00	6,447.93
1907	MBN-16	Surabaya	Kumai	Unnoted		
	MBN-17	Kumai	Surabaya	6,728.14	5,280.00	5,707.20
1908	MBN-18	Surabaya	Kumai	7,493.48	10,120.00	10,180.70
	MBN-19	Kumai	Semarang	7,120.00	5,208.00	5,420.89
	MBN-20	Semarang	Surabaya	Unnoted		
1909	MBN-21	Surabaya	Kumai	8,038.00	10,920.00	10,483.59
	MBN-22	Kumai	Semarang	6,088.99	8,850.40	10,224.73

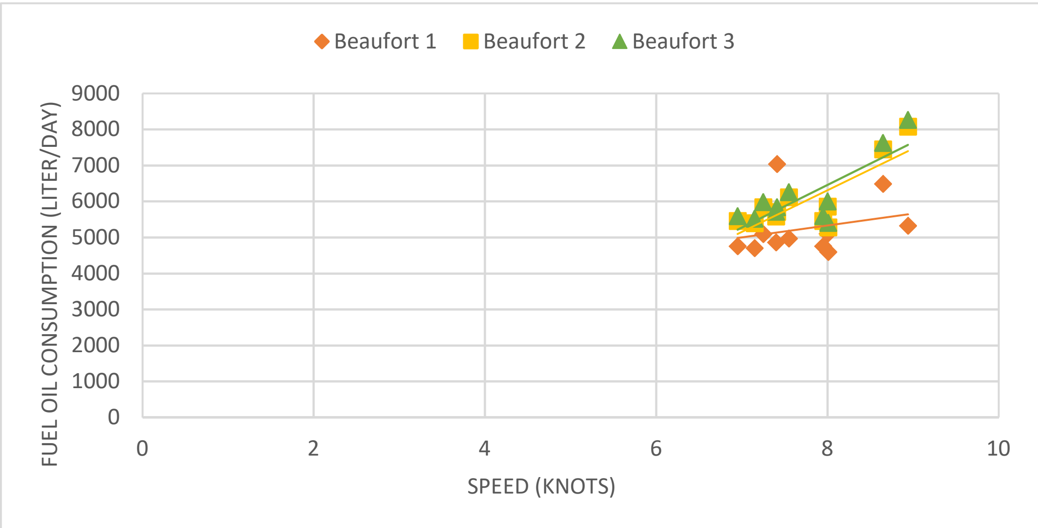
1909	MBN-23	Semarang	Surabaya	Unnoted		
1910	MBN-24	Surabaya	Kumai	Unnoted		
	MBN-25	Kumai	Semarang	5,889.77	5,398.86	6,377.09
				5,889.77	5,400.00	6,378.44
	MBN-26	Semarang	Surabaya	4,271.60	5,520.00	8,077.27

The first two correction resulted the first preliminary curve of fuel oil consumption estimation.



Weather Correction

Step 3: Classifying of Fuel Cons L to each sea state



Result of Fuel Cons L Classification

Bft 1

Speed	Fuel Cons L
6.6	10180.7
6.66	6377.0884
6.83	6378.4383
7.26	5857.8783
7.4	5586.1875
7.83	6447.9297
8	5862.1242
8.92	10483.592
8.94	8077.2747

Average 5938.5299

Bft 2

Speed	Fuel Cons L
6.95	5462.96
7.15	5394.91
7.95	5462.96
7.96	7378.467
8.01	5280.317
8.04	9700.582
8.65	7449.249

Average 6078.779

Bft 3

Speed	Fuel Cons L
6.1	4838.6361
7.41	5707.2041
7.55	6116.8739
7.75	10224.735
7.25	5844.5315
8.08	6203.5017

Average 6973.336

Bft 4

Speed	Fuel Cons L
5.06	8708.736
6.9	5420.888
7	5782.186
7.44	11489.76

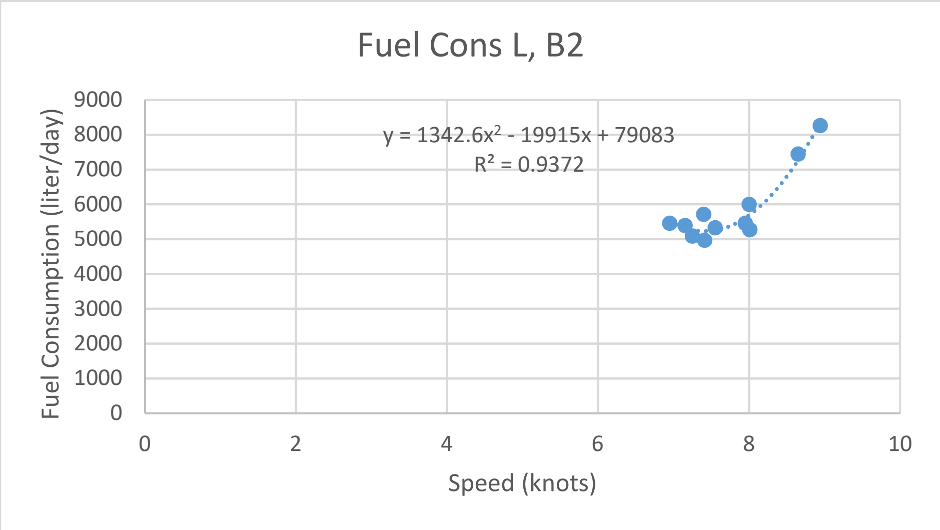
Average 8635.975

Step 4: Correction to Fuel Cons L towards weather condition

$$\text{Fuel Cons}_{L,B5} = \text{Fuel Cons}_{L} \times \frac{\text{Fuel Cons}_{B5}}{\text{Fuel Cons}_{B4/B6}}$$

<table>
<tr><th rowspan="2">Voyage Number</th><th rowspan="2">Trip Number</th><th colspan="2">Route</th><th rowspan="2">Fuel Cons L</th><th rowspan="2">Weather Force</th><th rowspan="2">Fuel Consumptio</th></tr>
<tr><th>Origin</th><th>Destination</th></tr>
<tr><td rowspan="3">1901</td><td>MBN-1</td><td>Surabaya</td><td>Kumai</td><td>5,857.88</td><td>1</td><td>5,996.22</td></tr>
<tr><td>MBN-2</td><td>Kumai</td><td>Semarang</td><td>5,844.53</td><td>3</td><td>5,094.78</td></tr>
<tr><td>MBN-3</td><td>Semarang</td><td>Surabaya</td><td>7,449.25</td><td>2</td><td>7,449.25</td></tr>
<tr><td rowspan="6">1902</td><td rowspan="3">MBN-4</td><td rowspan="3">Surabaya</td><td rowspan="3">Samarinda</td><td colspan="3">Unnoted</td></tr>
<tr><td>5,462.96</td><td>2</td><td>5,462.96</td></tr>
<tr><td>5,462.96</td><td>2</td><td>5,462.96</td></tr>
<tr><td rowspan="3">MBN-5</td><td rowspan="3">Samarinda</td><td rowspan="3">Surabaya</td><td>5,862.12</td><td>1</td><td>6,000.57</td></tr>
<tr><td>5,782.19</td><td>4</td><td>4,070.02</td></tr>
<tr><td>11,489.76</td><td>4</td><td>8,087.53</td></tr>
<tr><td rowspan="3">1903</td><td>MBN-6</td><td>Surabaya</td><td>Kumai</td><td>8,708.74</td><td>4</td><td>6,129.99</td></tr>
<tr><td>MBN-7</td><td>Kumai</td><td>Semarang</td><td>5,394.91</td><td>2</td><td>5,394.91</td></tr>
<tr><td>MBN-8</td><td>Semarang</td><td>Surabaya</td><td colspan="3">Unnoted</td></tr>
<tr><td rowspan="3">1904</td><td>MBN-9</td><td>Surabaya</td><td>Sampit</td><td>5,280.32</td><td>2</td><td>5,280.32</td></tr>
<tr><td></td><td></td><td></td><td>9,700.58</td><td>2</td><td>9,700.58</td></tr>
<tr><td>MBN-10</td><td>Sampit</td><td>Surabaya</td><td>7,378.47</td><td>2</td><td>7,378.47</td></tr>
<tr><td rowspan="4">1905</td><td>MBN-11</td><td>Surabaya</td><td>Semarang</td><td colspan="3">Unnoted</td></tr>
<tr><td rowspan="2">MBN-12</td><td rowspan="2">Semarang</td><td rowspan="2">Kumai</td><td>5,586.19</td><td>1</td><td>5,718.12</td></tr>
<tr><td>6,203.50</td><td>3</td><td>5,407.70</td></tr>
<tr><td>MBN-13</td><td>Kumai</td><td>Surabaya</td><td>6,116.87</td><td>3</td><td>5,332.19</td></tr>
<tr><td rowspan="2">1906</td><td>MBN-14</td><td>Surabaya</td><td>Kumai</td><td>4,838.64</td><td>3</td><td>4,217.92</td></tr>
<tr><td>MBN-15</td><td>Kumai</td><td>Surabaya</td><td>6,447.93</td><td>1</td><td>6,600.21</td></tr>
<tr><td rowspan="2">1907</td><td>MBN-16</td><td>Surabaya</td><td>Kumai</td><td colspan="3">Unnoted</td></tr>
<tr><td>MBN-17</td><td>Kumai</td><td>Surabaya</td><td>5,707.20</td><td>3</td><td>4,975.07</td></tr>
<tr><td rowspan="3">1908</td><td>MBN-18</td><td>Surabaya</td><td>Kumai</td><td>10,180.70</td><td>1</td><td>10,421.14</td></tr>
<tr><td>MBN-19</td><td>Kumai</td><td>Semarang</td><td>5,420.89</td><td>4</td><td>3,815.71</td></tr>
<tr><td>MBN-20</td><td>Semarang</td><td>Surabaya</td><td colspan="3">Unnoted</td></tr>
<tr><td rowspan="2">1909</td><td>MBN-21</td><td>Surabaya</td><td>Kumai</td><td>10,483.59</td><td>1</td><td>10,731.18</td></tr>
<tr><td>MBN-22</td><td>Kumai</td><td>Semarang</td><td>10,224.73</td><td>3</td><td>8,913.08</td></tr>
<tr><td>1909</td><td>MBN-23</td><td>Semarang</td><td>Surabaya</td><td colspan="3">Unnoted</td></tr>
<tr><td rowspan="4">1910</td><td>MBN-24</td><td>Surabaya</td><td>Kumai</td><td colspan="3">Unnoted</td></tr>
<tr><td rowspan="2">MBN-25</td><td rowspan="2">Kumai</td><td rowspan="2">Semarang</td><td>6,377.09</td><td>1</td><td>6,527.69</td></tr>
<tr><td>6,378.44</td><td>1</td><td>6,529.08</td></tr>
<tr><td>MBN-26</td><td>Semarang</td><td>Surabaya</td><td>8,077.27</td><td>1</td><td>8,268.03</td></tr>
</table>

The calculation is plotted into a graph:



Step 5: Classifying of Fuel Cons L, B2 to weather direction

Abbreviatio	Wind Directi	Degrees
NE	North East	45
SE	South East	135
S	South	180
SW	South West	225
W	West	270
NW	North West	315

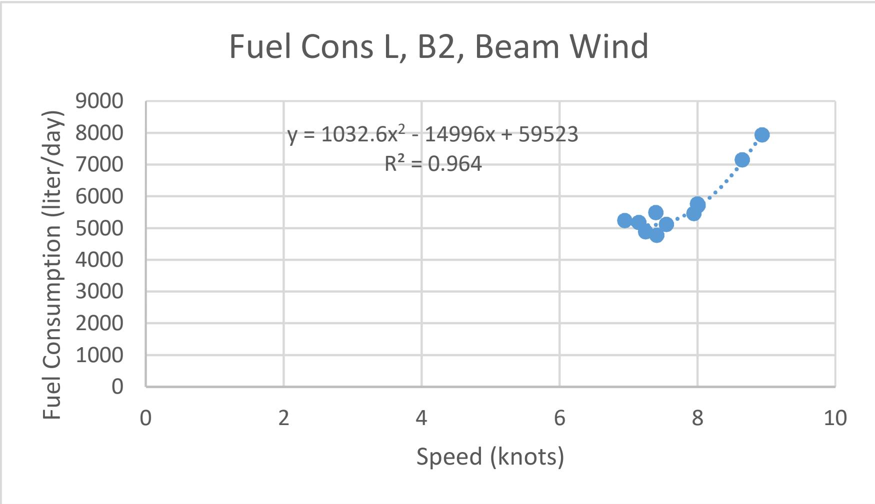
Relative Angle (α)
If (Wind Direction-Ship's Course>180) - α = |Wind Direction - Ship Course - 360|
If (Wind Direction-Ship's Course<-180) - α = |Wind Direction - Ship Course + 360|
Otherwise - α = |Wind Direction - Ship Course|

Voyage Number	Trip Number	Route		Relative Angle (α)		
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	-27	27	Head Wind
	MBN-2	Kumai	Semarang	26	26	Head Wind
	MBN-3	Semarang	Surabaya	56	56	Head Wind
1902	MBN-4	Surabaya	Samarinda	Unnoted		
				260	100	Beam Wind
				303	57	Head Wind
	MBN-5	Samarinda	Surabaya	-28	28	Head Wind
				-15	15	Head Wind
				-10	10	Head Wind
1903	MBN-6	Surabaya	Kumai	-72	72	Beam Wind
	MBN-7	Kumai	Semarang	26	26	Head Wind
	MBN-8	Semarang	Surabaya	Unnoted		
1904	MBN-9	Surabaya	Sampit	216	144	Tail Wind
				315	45	Head Wind
	MBN-10	Sampit	Surabaya	90	90	Beam Wind
1905	MBN-11	Surabaya	Semarang	Unnoted		
	MBN-12	Semarang	Kumai	-19	19	Head Wind
				307	53	Head Wind
	MBN-13	Kumai	Surabaya	-25	25	Head Wind
1906	MBN-14	Surabaya	Kumai	-25	25	Head Wind
	MBN-15	Kumai	Surabaya	155	155	Tail Wind
1907	MBN-16	Surabaya	Kumai	Unnoted		
	MBN-17	Kumai	Surabaya	-25	25	Head Wind
1908	MBN-18	Surabaya	Kumai	-27	27	Head Wind
	MBN-19	Kumai	Semarang	26	26	Head Wind
	MBN-20	Semarang	Surabaya	Unnoted		
1909	MBN-21	Surabaya	Kumai	308	52	Head Wind
	MBN-22	Kumai	Semarang	25	25	Head Wind
1909	MBN-23	Semarang	Surabaya	Unnoted		
1910	MBN-24	Surabaya	Kumai	Unnoted		
	MBN-25	Kumai	Semarang	-20	20	Head Wind
				-20	20	Head Wind
	MBN-26	Semarang	Surabaya	-59	59	Head Wind

Step 6: Correction to Fuel Cons L towards weather direction

Voyage Number	Trip Number	Route		Fuel Cons L, B2	Relative Angle	Fuel Cons L, B2, Beam
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	5,996.22	Head Wind	5751.3651
	MBN-2	Kumai	Semarang	5,094.78	Head Wind	4886.7334
	MBN-3	Semarang	Surabaya	7,449.25	Head Wind	7145.0565
1902	MBN-4	Surabaya	Samarinda	Unnoted		
				5,462.96	Beam Wind	5462.96
				5,462.96	Head Wind	5239.8783
	MBN-5	Samarinda	Surabaya	6,000.57	Head Wind	5755.5338
				4,070.02	Head Wind	3903.8241
				8,087.53	Head Wind	7757.2763
1903	MBN-6	Surabaya	Kumai	6,129.99	Beam Wind	6129.995
	MBN-7	Kumai	Semarang	5,394.91	Head Wind	5174.6073
	MBN-8	Semarang	Surabaya	Unnoted		
1904	MBN-9	Surabaya	Sampit	5,280.32	Tail Wind	5707.3905
				9,700.58	Head Wind	9304.4553
	MBN-10	Sampit	Surabaya	7,378.47	Beam Wind	7378.467
1905	MBN-11	Surabaya	Semarang	Unnoted		
	MBN-12	Semarang	Kumai	5,718.12	Head Wind	5484.6144
				5,407.70	Head Wind	5186.8758
	MBN-13	Kumai	Surabaya	5,332.19	Head Wind	5114.4446
1906	MBN-14	Surabaya	Kumai	4,217.92	Head Wind	4045.6836
	MBN-15	Kumai	Surabaya	6,600.21	Tail Wind	7134.0365
1907	MBN-16	Surabaya	Kumai	Unnoted		
	MBN-17	Kumai	Surabaya	4,975.07	Head Wind	4771.9111
1908	MBN-18	Surabaya	Kumai	10,421.14	Head Wind	9995.5852
	MBN-19	Kumai	Semarang	3,815.71	Head Wind	3659.8951
	MBN-20	Semarang	Surabaya	Unnoted		
1909	MBN-21	Surabaya	Kumai	10,731.18	Head Wind	10292.97
	MBN-22	Kumai	Semarang	8,913.08	Head Wind	8549.1117
1909	MBN-23	Semarang	Surabaya	Unnoted		
1910	MBN-24	Surabaya	Kumai	Unnoted		
	MBN-25	Kumai	Semarang	6,527.69	1	6261.1344
				6,529.08	1	6262.4598
	MBN-26	Semarang	Surabaya	8,268.03	1	7930.4063

The calculation is plotted into a graph:



The equation of the final correction then used for fuel oil consumption estimation

$$y = 1032.6x^2 - 14996x + 59523$$

Sailing Condition of MV Meratus Benoa

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Average Sail Speed
		Origin	Destination	Hours	Day	
1901	MBN-1	Surabaya	Kumai	33.400	1.392	9.106
	MBN-2	Kumai	Semarang	32.000	1.333	7.532
	MBN-3	Semarang	Surabaya	17.500	0.729	9.194
1902	MBN-4	Surabaya	Samarinda	63.500	2.646	8.086
	MBN-5	Samarinda	Surabaya	65.000	2.708	7.018
1903	MBN-6	Surabaya	Kumai	45.700	1.904	7.627
	MBN-7	Kumai	Semarang	34.400	1.433	7.087
	MBN-8	Semarang	Surabaya	21.200	0.883	8.321
1904	MBN-9	Surabaya	Sampit	28.800	1.200	7.375
	MBN-10	Sampit	Surabaya	29.300	1.221	7.61
1905	MBN-11	Surabaya	Semarang	22.600	0.942	8.567
	MBN-12	Semarang	Kumai	28.800	1.200	8.24
	MBN-13	Kumai	Surabaya	30.200	1.258	7.873
1906	MBN-14	Surabaya	Kumai	37.700	1.571	6.642
	MBN-15	Kumai	Surabaya	30.900	1.288	8.148
1907	MBN-16	Surabaya	Kumai	35.500	1.479	7.081
	MBN-17	Kumai	Surabaya	31.200	1.300	7.79
1908	MBN-18	Surabaya	Kumai	31.400	1.308	8.323
	MBN-19	Kumai	Semarang	31.500	1.313	7.703
	MBN-20	Semarang	Surabaya	20.200	0.842	7.683
1909	MBN-21	Surabaya	Kumai	26.800	1.117	8.663
	MBN-22	Kumai	Semarang	29.700	1.238	7.867
	MBN-23	Semarang	Surabaya	20.000	0.833	7.935
1910	MBN-24	Surabaya	Kumai	35.200	1.467	6.81
	MBN-25	Kumai	Semarang	35.200	1.467	6.726
	MBN-26	Semarang	Surabaya	19.200	0.800	8.229

Estimation of MV Meratus Benoa FOC using Bialystocki and Konovessis's Method

Voyage Number	Trip Number	Route		Actual FOC	;timation F(	Error
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	6,915.00	11,956.96	72.91%
	MBN-2	Kumai	Semarang	7,300.00	6,871.44	5.87%
	MBN-3	Semarang	Surabaya	5,134.00	6,515.16	26.90%
1902	MBN-4	Surabaya	Samarinda	13,795.00	15,293.55	10.86%
	MBN-5	Samarinda	Surabaya	23,028.00	13,918.18	39.56%
1903	MBN-6	Surabaya	Kumai	13,041.00	9,932.16	23.84%
	MBN-7	Kumai	Semarang	7,988.00	7,323.29	8.32%
	MBN-8	Semarang	Surabaya	4,240.00	5,509.81	29.95%
1904	MBN-9	Surabaya	Sampit	11,047.00	6,109.51	44.70%
	MBN-10	Sampit	Surabaya	6,944.00	6,352.58	8.52%
1905	MBN-11	Surabaya	Semarang	5,150.00	6,439.48	25.04%
	MBN-12	Semarang	Kumai	7,797.00	7,280.43	6.63%
	MBN-13	Kumai	Surabaya	6,553.00	6,875.92	4.93%
1906	MBN-14	Surabaya	Kumai	7,540.00	8,598.61	14.04%
	MBN-15	Kumai	Surabaya	6,694.00	7,583.13	13.28%
1907	MBN-16	Surabaya	Kumai	8,206.00	7,560.71	7.86%
	MBN-17	Kumai	Surabaya	6,864.00	6,976.53	1.64%
1908	MBN-18	Surabaya	Kumai	9,261.00	8,166.48	11.82%
	MBN-19	Kumai	Semarang	11,894.00	6,929.19	41.74%
	MBN-20	Semarang	Surabaya	4,554.00	4,428.47	2.76%
1909	MBN-21	Surabaya	Kumai	12,194.00	7,935.90	34.92%
	MBN-22	Kumai	Semarang	11,561.00	6,752.74	41.59%
	MBN-23	Semarang	Surabaya	4,534.00	4,622.17	1.94%
1910	MBN-24	Surabaya	Kumai	10,571.00	7,756.03	26.63%
	MBN-25	Kumai	Semarang	8,139.00	7,881.54	3.16%
	MBN-26	Semarang	Surabaya	4,416.00	4,835.93	9.51%
					Average	19.958%

Sailing Condition of MV Meratus Benoa

Voyage Number	Trip Number	Route		Duration of Sea Voyage		Average Sail Speed
		Origin	Destination	Hours	Day	
1901	MBT-1	Semarang	Pontianak	54.400	3.400	7.57
	MBT-2	Pontianak	Semarang	47.300	1.971	8.508
1902	MBT-3	Semarang	Pontianak	56.200	2.342	7.263
	MBT-4	Pontianak	Semarang	45.000	1.875	9.053
1903	MBT-5	Semarang	Pontianak	49.900	2.079	8.036
	MBT-6	Pontianak	Surabaya	53.200	2.217	8.506
1904	MBT-7	Surabaya	Sampit	28.000	1.167	7.743
	MBT-8	Sampit	Surabaya	24.500	1.021	8.193
1905	MBT-9	Surabaya	Kumai	30.200	1.258	8.363
	MBT-10	Kumai	Semarang	29.600	1.233	7.48
	MBT-11	Semarang	Surabaya	15.500	0.646	8.048
1906	MBT-12	Surabaya	Sampit	27.000	1.125	7.089
	MBT-13	Sampit	Surabaya	23.400	0.975	8.057
1907	MBT-14	Surabaya	Sampit	19.300	0.804	8.248
	MBT-15	Sampit	Surabaya	24.000	1.000	9.403
1908	MBT-16	Surabaya	Kumai	31.000	1.292	7.304
	MBT-17	Kumai	Surabaya	24.500	1.021	8.806
1909	MBT-18	Surabaya	Semarang	20.100	0.838	7.038
	MBT-19	Semarang	Kumai	24.400	1.017	8.117
	MBT-20	Kumai	Surabaya	23.000	0.958	8.768
1910	MBT-21	Surabaya	Semarang	12.000	0.500	9.587
	MBT-22	Semarang	Kumai	27.300	1.138	7.883
	MBT-23	Kumai	Surabaya	27.400	1.142	8.361

Estimation of MV Meratus Benoa FOC using Bialystocki and Konovessis's Method

Voyage Number	Trip Number	Route		Actual FOC	Estimation FOC	Error
		Origin	Destination			
1901	MBT-1	Semarang	Pontianak	11,968.00	17,599.49	47.05%
	MBT-2	Pontianak	Semarang	10,406.00	13,170.85	26.57%
1902	MBT-3	Semarang	Pontianak	12,688.00	11,890.77	6.28%
	MBT-4	Pontianak	Semarang	9,900.00	15,736.52	58.95%
1903	MBT-5	Semarang	Pontianak	17,694.00	11,846.38	33.05%
	MBT-6	Pontianak	Surabaya	11,704.00	14,802.32	26.47%
1904	MBT-7	Surabaya	Sampit	6,160.00	6,203.78	0.71%
	MBT-8	Sampit	Surabaya	5,390.00	6,098.77	13.15%
1905	MBT-9	Surabaya	Kumai	6,644.00	7,966.83	19.91%
	MBT-10	Kumai	Semarang	6,512.00	6,323.67	2.89%
	MBT-11	Semarang	Surabaya	3,410.00	3,692.23	8.28%
1906	MBT-12	Surabaya	Sampit	5,940.00	5,747.12	3.25%
	MBT-13	Sampit	Surabaya	5,148.00	5,588.42	8.56%
1907	MBT-14	Surabaya	Sampit	4,246.00	4,891.95	15.21%
	MBT-15	Sampit	Surabaya	5,280.00	9,814.40	85.88%
1908	MBT-16	Surabaya	Kumai	6,820.00	6,561.40	3.79%
	MBT-17	Kumai	Surabaya	5,390.00	7,698.97	42.84%
1909	MBT-18	Surabaya	Semarang	4,422.00	4,295.86	2.85%
	MBT-19	Semarang	Kumai	5,368.00	5,931.26	10.49%
	MBT-20	Kumai	Surabaya	5,060.00	7,112.86	40.57%
1910	MBT-21	Surabaya	Semarang	5,280.00	5,331.60	0.98%
	MBT-22	Semarang	Kumai	6,006.00	6,230.13	3.73%
	MBT-23	Kumai	Surabaya	6,028.00	7,223.00	19.82%
					Average	20.926%

ATTACHMENT 2:

FUEL OIL CONSUMPTION ESTIMATION (Moreno-Gutiérrez, et al.)

Resistance Calculation

Ship Particular		
General		
Vessel Nam	MV Meratus Benoa	
Type of Ves	Container Deck Ship	
Owner	PT. Meratus Line	
Flag	Indonesia	
IMO-Numb	9509231	
MMSI	525025061	
GRT	3668	GT
Summer D\	5161	Ton
Summer Di	7561	Ton
LOA	107.68	Meter
LPP	99.09	Meter
Breadth M	20.6	Meter
Depth Mou	6	Meter
Summer Dr	4.35	Meter
Speed	10	Knot
Classificati	NK/BKI	
Machinery		
Main Engin	Yanmar 6EY26 - 2 x 14	
Propeller	Fixed; 4 blades; 2 x 2.7	
Auxiliary Er	HND MWM Henan Die	

Base of Calculation

$$C_b = 0.70 + 1/8\tan^{-1}\frac{(23-100F_n)}{4}\,radians$$

$$Fn = \frac{V}{\sqrt{g \cdot L}}$$

$$Rn = \frac{V \cdot L_{wl}}{\nu}$$

C_b = 0.801

Fn = 0.18796

Rn 675,736,944.19

$$S = 1.53 \cdot (\frac{\nabla}{T} \cdot 1.9 \cdot L_{wl} \cdot T)$$

S = 2964.583 m2

Total resistance of ship could be calculated using the original formula from ITTC1957:

$$R_T = \frac{1}{2} \cdot C_T \cdot \rho \cdot S \cdot V^2$$

$$C_T = C_F + C_A + C_{AA} + C_R$$

Calculation of frictional resistance coefficient

$$C_F = \frac{0.075}{(logR_n - 2)^2}$$

C_F = 0.001608

Calculation of incremental resistance coefficient

$$C_A = \frac{0.5 \cdot \log(\Delta) - 0.1 \cdot (\log(\Delta))^2}{1000}$$

C_A = 0.000435

Calculation of air resistance specifically for container vessels

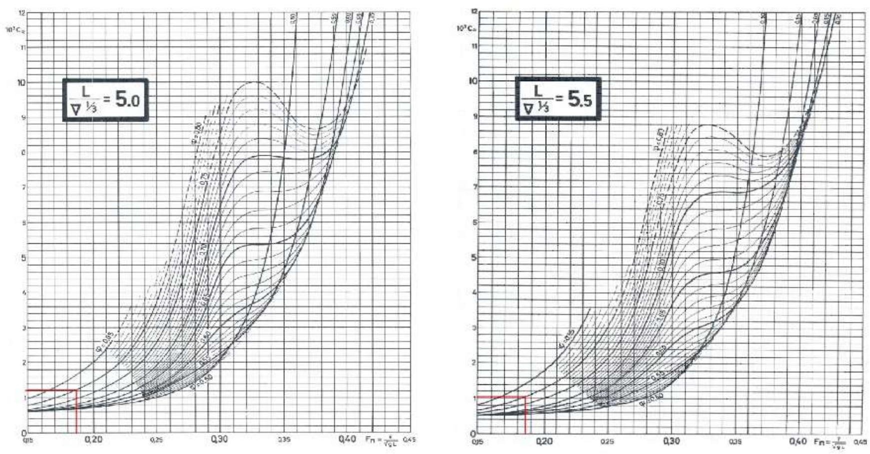
$$C_{AA} = \frac{0.28 \cdot TEU^{-0.126}}{1000}$$

C_{AA} = 0.000133

Calculation of residual resistance with modification

$$C_R = C_{R,Diagram} + \Delta C_{R,B/T=2.5} + \Delta C_{R,LCB} + \Delta C_{R,form} +$$

$C_{R,Diagram}$



$C_{R,Diagram}$ = 1.11302

$\Delta C_{R,\frac{B}{T}\mp 2.5} = 0.16(\frac{B}{T} - 2.5) \cdot 10^{-3}$

$\Delta C_{R,\frac{B}{T}\mp 2.5}$ = 0.0003

$\Delta C_{R,Bulb} = (250 \cdot Fn - 90) \cdot C_R$ *Harvald no bulbous bow*

$\Delta C_{R,Bulb}$ = -0.4787

$\Delta C_{R,LCB}$ = Ignored

$\Delta C_{R,Form}$ = Ignored

C_R = 0.63462

Total resistance coefficient

C_T = 0.636796

The ship's total resistance

R_T = 33,863

Determining the ship's propulsive efficiency

$$P_E = R_T \cdot V$$

P_E = 200,339 kN

η_H = 1.02

$$P_T = \frac{P_E}{\eta_H}$$

P_T = 196,411 kN

η_R = 0.7

η_O = 0.98

$$P_D = \frac{P_T}{\eta_R \cdot \eta_O}$$

P_D = 286,314 kN

$$\eta_D = \frac{P_E}{P_D}$$

η_D = 0.69972

Modifcation of propulsive efficiency according to Moreno-Gutiérrez, et al.

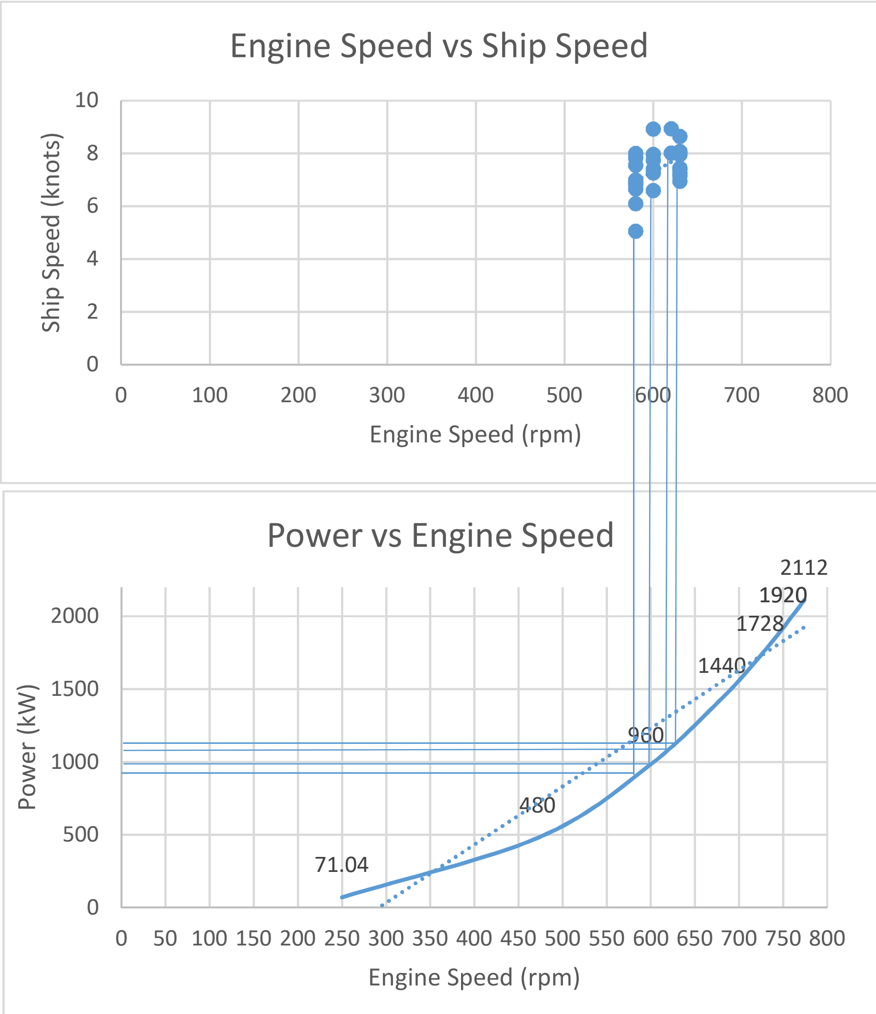
$$\eta_f = \eta_D - 9\%$$

$$\eta_w = \eta_D - 10\%$$

η_f = 0.6098

η_w = 0.5998

Estimation of Main Engine Power



From the estimation using data of shop test and noon report, main engine power during operation could be obtained

RPM	Power (kW)
580	897.32
600	993.14
620	1086.30
630	1143.10

Calculation of Power Transient, Load Factor, and SFOC

$$P_{transient} = \frac{P_1 (\frac{t_{transient}}{t_1})^{(\frac{2}{3})} (\frac{V_{transient}}{V_1})^n}{\eta_w \eta_f}$$

$$LF = \frac{P_{transient}}{P_1}$$

$$SFOC = SFOC_{relative} \times SFOC_{base}$$

$$SFOC_{relative} = 0.455LF^2 - 0.71LF + 1.28$$

MV Meratus Benoa

Voyage Number	Trip Number	Route		Ptransient	Load Factor	SFOC Relative	SFOC
		Origin	Destination				
1901	MBN-1	Surabaya	Kumai	1620.94	0.844	1.005	200.977
	MBN-2	Kumai	Semarang	1669.26	0.869	1.007	201.328
	MBN-3	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1902	MBN-4	Surabaya	Samarinda	1463.65	0.762	1.003	200.634
	MBN-5	Samarinda	Surabaya	1734.90	0.904	1.010	201.989
1903	MBN-6	Surabaya	Kumai	501.36	0.261	1.126	225.125
	MBN-7	Kumai	Semarang	1655.64	0.862	1.006	201.218
	MBN-8	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1904	MBN-9	Surabaya	Sampit	2417.32	1.259	1.107	221.466
	MBN-10	Sampit	Surabaya	1737.05	0.905	1.010	202.015
1905	MBN-11	Surabaya	Semarang	2353.36	1.226	1.093	218.664
	MBN-12	Semarang	Kumai	2579.69	1.344	1.147	229.486
	MBN-13	Kumai	Surabaya	1826.35	0.951	1.016	203.265
1906	MBN-14	Surabaya	Kumai	964.45	0.502	1.038	207.632
	MBN-15	Kumai	Surabaya	1883.22	0.981	1.021	204.267
1907	MBN-16	Surabaya	Kumai	1275.53	0.664	1.009	201.826
	MBN-17	Kumai	Surabaya	1801.79	0.938	1.014	202.882
1908	MBN-18	Surabaya	Kumai	1275.53	0.664	1.009	201.826
	MBN-19	Kumai	Semarang	1444.48	0.752	1.003	200.675
	MBN-20	Semarang	Surabaya	2353.36	1.226	1.093	218.664
1909	MBN-21	Surabaya	Kumai	3785.15	1.971	1.649	329.732
	MBN-22	Kumai	Semarang	2019.35	1.052	1.037	207.313
	MBN-23	Semarang	Surabaya	2674.39	1.393	1.174	234.765
1910	MBN-24	Surabaya	Kumai	3785.15	1.971	1.649	329.732
	MBN-25	Kumai	Semarang	1262.72	0.658	1.010	201.971
	MBN-26	Semarang	Surabaya	2674.39	1.393	1.174	234.765

MV Meratus Bontang

Voyage Number	Trip Number	Route		Ptransient	Load Factor	SFOC Relative	SFOC
		Origin	Destination				
1901	MBT-1	Semarang	Pontianak	1155.71	0.602	1.017	203.497
	MBT-2	Pontianak	Semarang	1788.60	0.932	1.013	202.689
1902	MBT-3	Semarang	Pontianak	1534.91	0.799	1.003	200.638
	MBT-4	Pontianak	Semarang	2562.49	1.335	1.143	228.575
1903	MBT-5	Semarang	Pontianak	1840.86	0.959	1.018	203.506
	MBT-6	Pontianak	Surabaya	2766.37	1.441	1.202	240.316
1904	MBT-7	Surabaya	Sampit	1806.68	0.941	1.015	202.956
	MBT-8	Sampit	Surabaya	1911.75	0.996	1.024	204.830
1905	MBT-9	Surabaya	Kumai	1502.57	0.783	1.003	200.605
	MBT-10	Kumai	Semarang	1588.32	0.827	1.004	200.806
	MBT-11	Semarang	Surabaya	1435.22	0.748	1.004	200.702
1906	MBT-12	Surabaya	Sampit	1806.68	0.941	1.015	202.956
	MBT-13	Sampit	Surabaya	1911.75	0.996	1.024	204.830
1907	MBT-14	Surabaya	Sampit	2309.49	1.203	1.084	216.859
	MBT-15	Sampit	Surabaya	1832.23	0.954	1.017	203.362
1908	MBT-16	Surabaya	Kumai	588.57	0.307	1.105	221.022
	MBT-17	Kumai	Surabaya	2220.67	1.157	1.067	213.495
1909	MBT-18	Surabaya	Semarang	1111.38	0.579	1.021	204.295
	MBT-19	Semarang	Kumai	2280.12	1.188	1.079	215.704
	MBT-20	Kumai	Surabaya	2830.74	1.474	1.222	244.449
1910	MBT-21	Surabaya	Semarang	1111.38	0.579	1.021	204.295
	MBT-22	Semarang	Kumai	2280.12	1.188	1.079	215.704
	MBT-23	Kumai	Surabaya	2220.667	1.157	1.067	213.495

MV Meratus Benoa Sailing Condition

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea	M/E FOC (Ton)
		Origin	Destination				
1901	MBN-1	Surabaya	Kumai	993.14	0.1996	33.400	6.667
	MBN-2	Kumai	Semarang	1143.07	0.2301	32.000	7.364
	MBN-3	Semarang	Surabaya	1143.07	0.2499	17.500	4.374
1902	MBN-4	Surabaya	Samarinda	1143.07	0.2293	63.500	14.563
	MBN-5	Samarinda	Surabaya	1143.07	0.2309	65.000	15.008
1903	MBN-6	Surabaya	Kumai	897.32	0.2020	45.700	9.232
	MBN-7	Kumai	Semarang	1143.07	0.2300	34.400	7.912
	MBN-8	Semarang	Surabaya	1143.07	0.2499	21.200	5.299
1904	MBN-9	Surabaya	Sampit	1143.07	0.2532	28.800	7.291
	MBN-10	Sampit	Surabaya	993.14	0.2006	29.300	5.878
1905	MBN-11	Surabaya	Semarang	1143.07	0.2499	22.600	5.649
	MBN-12	Semarang	Kumai	1143.07	0.2623	28.800	7.555
	MBN-13	Kumai	Surabaya	897.32	0.1824	30.200	5.508
1906	MBN-14	Surabaya	Kumai	897.32	0.1863	37.700	7.024
	MBN-15	Kumai	Surabaya	897.32	0.1833	30.900	5.664
1907	MBN-16	Surabaya	Kumai	993.14	0.2004	35.500	7.116
	MBN-17	Kumai	Surabaya	993.14	0.2015	31.200	6.286
1908	MBN-18	Surabaya	Kumai	993.14	0.2004	31.400	6.294
	MBN-19	Kumai	Semarang	897.32	0.1801	31.500	5.672
	MBN-20	Semarang	Surabaya	1143.07	0.2499	20.200	5.049
1909	MBN-21	Surabaya	Kumai	993.14	0.3275	26.800	8.776
	MBN-22	Kumai	Semarang	993.14	0.2059	29.700	6.115
	MBN-23	Semarang	Surabaya	1086.29	0.2550	20.000	5.100
1910	MBN-24	Surabaya	Kumai	993.14	0.3275	35.200	11.527
	MBN-25	Kumai	Semarang	897.32	0.1812	35.200	6.379
	MBN-26	Semarang	Surabaya	1086.29	0.2550	19.200	4.896

Estimation of MV Meratus Benoa FOC using Moreno-Gutiérrez, et al.'s Method

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destination			
1901	MBN-1	Surabaya	Kumai	6.667	6.853	2.72%
	MBN-2	Kumai	Semarang	7.364	7.234	1.80%
	MBN-3	Semarang	Surabaya	4.374	5.088	14.03%
1902	MBN-4	Surabaya	Samarinda	14.563	13.671	6.53%
	MBN-5	Samarinda	Surabaya	15.008	22.821	34.24%
1903	MBN-6	Surabaya	Kumai	9.232	12.924	28.57%
	MBN-7	Kumai	Semarang	7.912	7.916	0.05%
	MBN-8	Semarang	Surabaya	5.299	4.202	26.11%
1904	MBN-9	Surabaya	Sampit	7.291	10.948	33.40%
	MBN-10	Sampit	Surabaya	5.878	6.882	14.58%
1905	MBN-11	Surabaya	Semarang	5.649	5.104	10.68%
	MBN-12	Semarang	Kumai	7.555	7.727	2.23%
	MBN-13	Kumai	Surabaya	5.508	6.494	15.18%
1906	MBN-14	Surabaya	Kumai	7.024	7.472	6.00%
	MBN-15	Kumai	Surabaya	5.664	6.634	14.62%
1907	MBN-16	Surabaya	Kumai	7.116	8.132	12.50%
	MBN-17	Kumai	Surabaya	6.286	6.802	7.58%
1908	MBN-18	Surabaya	Kumai	6.294	9.178	31.42%
	MBN-19	Kumai	Semarang	5.672	11.787	51.88%
	MBN-20	Semarang	Surabaya	5.049	4.513	11.88%
1909	MBN-21	Surabaya	Kumai	8.776	12.084	27.38%
	MBN-22	Kumai	Semarang	6.115	11.457	46.63%
	MBN-23	Semarang	Surabaya	5.100	4.493	13.52%
1910	MBN-24	Surabaya	Kumai	11.527	10.476	10.03%
	MBN-25	Kumai	Semarang	6.379	8.066	20.91%
	MBN-26	Semarang	Surabaya	4.896	4.376	11.89%
					Average	17.55%

MV Meratus Bontang Sailing Condition

Voyage Number	Trip Number	Route		Power (kW)	FOC (kg/hour)	Duration of Sea	M/E FOC (Ton)
		Origin	Destination				
1901	MBT-1	Semarang	Pontianak	1143.065	0.2326	54.4	12.654
	MBT-2	Pontianak	Semarang	1143.065	0.2317	47.3	10.959
1902	MBT-3	Semarang	Pontianak	1143.065	0.2293	56.2	12.889
	MBT-4	Pontianak	Semarang	1143.065	0.2613	45.0	11.757
1903	MBT-5	Semarang	Pontianak	1143.065	0.2326	49.9	11.608
	MBT-6	Pontianak	Surabaya	1143.065	0.2747	53.2	14.614
1904	MBT-7	Surabaya	Sampit	1143.065	0.2320	28.0	6.496
	MBT-8	Sampit	Surabaya	1143.065	0.2341	24.5	5.736
1905	MBT-9	Surabaya	Kumai	1143.065	0.2293	30.2	6.925
	MBT-10	Kumai	Semarang	1143.065	0.2295	29.6	6.794
	MBT-11	Semarang	Surabaya	1143.065	0.2294	15.5	3.556
1906	MBT-12	Surabaya	Sampit	1143.065	0.2320	27.0	6.264
	MBT-13	Sampit	Surabaya	1143.065	0.2341	23.4	5.479
1907	MBT-14	Surabaya	Sampit	1143.065	0.2479	19.3	4.784
	MBT-15	Sampit	Surabaya	1143.065	0.2325	24.0	5.579
1908	MBT-16	Surabaya	Kumai	1143.065	0.2526	31.0	7.832
	MBT-17	Kumai	Surabaya	1143.065	0.2440	24.5	5.979
1909	MBT-18	Surabaya	Semarang	1143.065	0.2335	20.1	4.694
	MBT-19	Semarang	Kumai	1143.065	0.2466	24.4	6.016
	MBT-20	Kumai	Surabaya	1143.065	0.2794	23.0	6.427
1910	MBT-21	Surabaya	Semarang	1143.065	0.2335	12.0	2.802
	MBT-22	Semarang	Kumai	1143.065	0.2466	27.3	6.731
	MBT-23	Kumai	Surabaya	1143.065	0.2440	27.4	6.687

Estimation of MV Meratus Bontang FOC using Moreno-Gutiérrez, et al.'s Method

Voyage Number	Trip Number	Route		Estimation FOC (Ton)	Actual FOC (Ton)	Error
		Origin	Destinatior			
1901	MBT-1	Semarang	Pontianak	12.654	11.860	6.69%
	MBT-2	Pontianak	Semarang	10.959	10.312	6.27%
1902	MBT-3	Semarang	Pontianak	12.889	12.574	2.51%
	MBT-4	Pontianak	Semarang	11.757	9.811	19.84%
1903	MBT-5	Semarang	Pontianak	11.608	17.535	33.80%
	MBT-6	Pontianak	Surabaya	14.614	11.599	26.00%
1904	MBT-7	Surabaya	Sampit	6.496	6.105	6.41%
	MBT-8	Sampit	Surabaya	5.736	5.341	7.39%
1905	MBT-9	Surabaya	Kumai	6.925	6.584	5.18%
	MBT-10	Kumai	Semarang	6.794	6.453	5.28%
	MBT-11	Semarang	Surabaya	3.556	3.379	5.23%
1906	MBT-12	Surabaya	Sampit	6.264	5.887	6.41%
	MBT-13	Sampit	Surabaya	5.479	5.102	7.39%
1907	MBT-14	Surabaya	Sampit	4.784	4.208	13.70%
	MBT-15	Sampit	Surabaya	5.579	5.232	6.62%
1908	MBT-16	Surabaya	Kumai	7.832	6.759	15.88%
	MBT-17	Kumai	Surabaya	5.979	5.341	11.93%
1909	MBT-18	Surabaya	Semarang	4.694	4.382	7.11%
	MBT-19	Semarang	Kumai	6.016	5.320	13.09%
	MBT-20	Kumai	Surabaya	6.427	5.014	28.16%
1910	MBT-21	Surabaya	Semarang	2.802	5.232	46.44%
	MBT-22	Semarang	Kumai	6.731	5.952	13.09%
	MBT-23	Kumai	Surabaya	6.687	5.974	11.93%
					Average	13.32%